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(Terms expire January 1, 1927; except as otherwise noted)

37 West 39th Street
New York, N. Y.

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INSTITUTE ACTIVITIES

Chicago Section

At the November meeting of the Chicago Section, held in the Monadnock Building, a paper on "Short Wave Transmitters and Antenna Models" was presented by Prof. J. T. Tykociner, of the University of Illinois. A second paper on the subject "A New Wavemeter for Radio Measurements" was presented by Prof. Tykociner and L. P. Gardner.

Board Meeting, December 1

The December meeting of the Board of Direction, held at Institute headquarters, New York, was attended by Dr. J. H. Dellinger, president; Donald McNicol, vice-president; Alfred N. Goldsmith, secretary; W. F. Hubley, treasurer; J. V. L. Hogan, L. A. Hazeltine, and Lloyd Espenschied, managers. Committee chairmen, making reports to the Board at this meeting, and who were present, were: Ralph Bown, L. E. Whittemore and R. H. Marriott.

Year Book

The Year Book for 1926 will be issued about the middle of February. This publication will contain a complete list of the members of the Institute, all grades; the Constitution, Section By-laws, and other matter of interest to all who are identified with the Institute, and who are interested in radio.

The publication is free to all Fellows, Members and Associates. A copy is being mailed to each member in these grades.

Price to others, fifty cents per copy.

Committees for Year 1926

In this issue of the PROCEEDINGS appears a list of working committees for the year 1926, appointed by the President.

Members of the Institute may communicate direct with committee chairman on matters pertaining to the work of the respective committees. The rapid increase in membership in the Institute in recent years will very likely continue throughout the present and coming years. With the membership as large as it is now, the work of the committees is of considerable proportions, and requires the continuous attention of the respective chairmen and of committee members.

Elections and Transfers

At the December, 1925, Board meeting, the following transfers and elections were approved: Transferred to grade of Fellow: Dr. Ralph Bown and Lester Jones. Transferred to grade of Member: D. Hepburn and Isaac R. Lounsberry. Elected to grade of Member: W. E. Branch, Walter J. Brown, George P. Bush, O. E. Dunlap, F. E. Eldredge, Walter H. Eller, J. H. Reyner.

At the January, 1926, Board meeting sixty applications for Associate grade and six applications for Junior grade were approved.

January Meeting of Board of Direction

At the regular monthly meeting of the Board of Direction, held January 5, the following members were present: Dr. J. H. Dellinger, Dr. A. N. Goldsmith and Messrs. Donald McNicol, Lloyd Espenschied, J. V. L. Hogan, Melville Eastham, W. F. Hubley, R. H. Marriott and L. E. Whittemore.

The count of the election ballots showed that the membership at large had elected as officers for the year 1926: Mr. Donald McNicol, President; Dr. Ralph Bown, Vice-president, and as Managers, Messrs. R. H. Marriott and L. E. Whittemore. The three appointive Managers, and one to fill the unexpired term of Dr. H. W. Nichols, deceased, are: Louis A. Hazeltine, Lloyd Espenschied, J. V. L. Hogan and George Lewis.

Certificates of Membership

At the January, 1926, meeting of the Board of Direction, proposal was approved to issue Certificates of Membership to Fellows and Members, and membership cards to Associates. The former will be suitably engrossed, will show the name of the member, and be signed by the President and Secretary of the Institute.

The certificates and cards will be ready for distribution about March 1, next, and may be obtained upon request to the Secretary.

Annual Meeting, 1926

The Annual Meeting of the Institute for 1926 was held in the form of a Convention on January 18, 19, in the Engineering Societies Building, New York. A paper on "The Polarization of Radio Waves" was presented by Mr. G. W. Pickard, and a paper on "The Present Status of Radio Atmospheric Disturbances," by Dr. L. W. Austin.

At the evening session, January 18, was presented a Symposium on "The Results of the Washington Radio Conference of November, 1925," the various viewpoints being discussed by Dr. Alfred N. Goldsmith, Dr. J. H. Dellinger, Mr. J. V. L. Hogan and Mr. R. H. Marriott.

Organized trips of inspection were made to the new high-power broadcasting station of the Radio Corporation of America at Bound Brook, N. J.; the trans-ocean radio telegraph office of the Radio Corporation of America in New York; Broadcast Station WEAF of the American Telephone and Telegraph Company; the Bell Laboratories Station WJZ, New York, of the Radio Corporation of America; the Studio and Station of WAHG, and manufacturing plant of A. H. Grebe Company, Richmond Hill, N. Y.

On the evening of January 19, there was a banquet at the Waldorf-Astoria Hotel, New York, at which the dinner music was received by radio, and at which the following radio engineers and executives delivered short addresses: Dr. Irving Langmuir, Dr. F. B. Jewett, Dr. A. E. Kennelly, Dr. E. F. W. Alexanderson, Prof. J. H. Morecroft, Mr. Edward J. Nally and Mr. A. H. Grebe.

Report of Standardization Committee

The Report of the Standardization Committee, to be known as the 1926 Report, is now ready for distribution. The Report contains a list of definitions of radio terms prepared by the Committee; also, approved symbols illustrating circuit elements and apparatus parts. Copies are included as a supplement to this issue of the PROCEEDINGS. Price to non-members, one dollar per copy.

Technical Papers for Presentation or Publication

It is important that all papers intended for presentation at meetings or for publication in the PROCEEDINGS be forwarded to the Chairman of the Meetings and Papers Committee at least sixty days before the date of presentation. This, in order to allow time for review, editing, making of illustrating cuts, printing, scheduling, etc. Illustrations must be clear enough to reproduce clearly as line cuts or half-tones, and must be of sizes such that they will still be clear when reduced to the width of the PROCEEDINGS page. Only sufficient illustrations must be used as are necessary to clarify the text.

TRANSATLANTIC RADIO TELEPHONE TRANSMISSION*

By

Lloyd Espenschied, C. N. Anderson, and Austin Bailey

(Department of Development and Research, American Telephone and Telegraph Company, New York)

Introduction

It will be recalled that something over two years ago, experiments in one-way radio telephone transmission were conducted from the United States to England.[1] In respect to the clarity

*Presented before The Institute of Radio Engineers, New York, May 6, 1925. Received by the Editor, May 28, 1925.

[1] "Trans-Atlantic Radio Telephony," Arnold and Espenschied, "Journal of the American Institute of Electrical Engineers," August, 1923. See also, "Power Amplifiers in Transatlantic Telephony," Oswald and Schelleng, Proceedings of The Institute of Radio Engineers.

and uniformity of the reception obtained in Europe, the results represented a distinct advance in the art over the trans-Atlantic tests of 1915. However, they were carried out during the winter, which is most favorable to radio transmission, and it was realized that an extensive study of the transmission obtainable during less favorable times would be required before the development of a trans-Atlantic radio telephone service could be undertaken upon a sound engineering basis. Consequently, an extended program of measurements was initiated to disclose the transmission conditions obtaining thruout the twenty-four hours of the day and the various seasons of the year. The methods used in conducting these measurements and the results obtained during the first few months of them have already been described in the paper previously mentioned. The results there reported upon were limited to one-way transmission from the United States to England upon the telephone channel. Since then measurements have extended to include transmission on several frequencies in each direction from radio telegraph stations, in addition to the 57 kilocycles employed by the telephone channel.

The present paper is, therefore, in the nature of a report upon the results thus far obtained in work currently under way. It seems desirable to make public these results because of the large amount of valuable data which they have already yielded, and because of the timely interest which attaches to information bearing upon the fundamentals of radio transmission. The carrying on of this extensive measurement program has been made possible thru the co-operation of engineers of the following organizations: in the United States—The American Telephone and Telegraph Company and the Bell Telephone Laboratories, Incorporated, with the Radio Corporation of America and its Associated Companies; in England—the International Western Electric Company, Incorporated, and the British Post Office.

Measurement Program

The scene of these trans-Atlantic experiments is shown in Figure 1. The British terminal stations will be seen to lie in the vicinity of London and the American stations in the northeastern part of the United States. The United States transmitting stations are the radio telephone transmitter at Rocky Point, Long Island, and the normal radio telegraph transmitters at Rocky Point and at Marion, Massachusetts. The measurements of these stations were made at New Southgate and at Chedzoy England. The British transmitting stations utilized in measur-

ing the east-to-west transmission were the British Post Office telegraph stations at Leafield and at Northolt. The receiving measurements in the United States were initiated at Green Harbor, Massachusetts, and continued at Belfast, Maine, and Riverhead, Long Island.

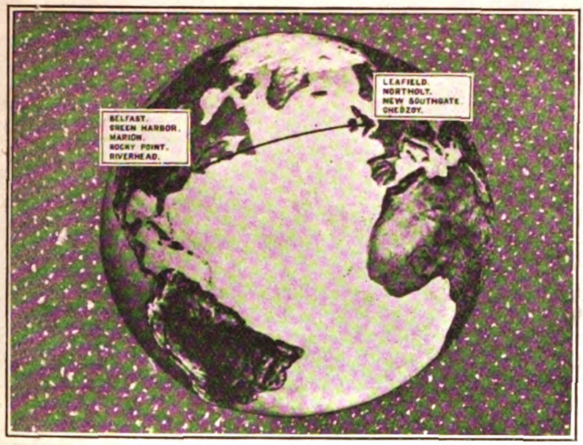


FIGURE 1

The Riverhead receiving station, shown in Figures 2 and 3, is typical of the receiving stations involved in the measurement program. The interior view of Figure 3 shows the group of receiving measurement apparatus at the right and the loop at the left. The three bays of apparatus shown are as follows: That at the left is the receiving set proper which is, in reality, two receiving sets in one, arranged so that one may be set for measurements on one frequency band and the other set upon another band. Th eset is provided with variable filters which accounts for the considerable number of condenser dials. The second bay from the left contains voice-frequency output apparatus, cathode ray oscilligraph and frequency meter. The third bay mounts the source of local signal and means for attenuating it, and the fourth bay contains means for monitoring the transmission from the nearby Rocky Point radio telephone transmitter.

The measurements made are of two quantities: (1), the strength of received field, and (2), the strength of received noise caused by static. The particular frequencies upon which the measurements were taken are given in the chart of Figure 4. They lie in a range between 15 and 60 kc. The arrows indicate the single frequency transmissions which were employed for signal

FIGURE 2

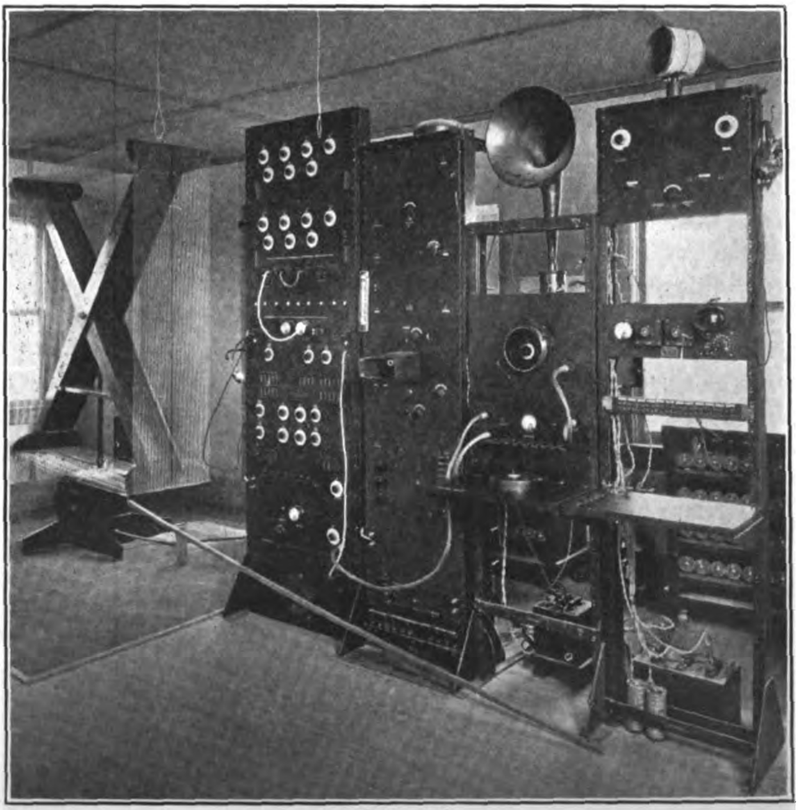


FIGURE 3

field strength meausrements, those at the left indicating the frequencies received in the United States from England, and those at the right, the frequencies received in England from the United States. The black squares in the chart denote the bands in which the noise measurements were taken. In general, the measurements of both field strength and noise have been carried out on both sides of the Atlantic at hourly intervals for one day each week. The data presented herewith are assembled from some 40,000 individual measurements taken during the past two years in the frequency range noted above. The transmitting antenna current has been obtained for each individual field strength measurement and all values corrected to a definite reference antenna current for each station measured. The data have been subject to careful analysis in order to disclose what physical factors, such as sunlight and the earth's magnetic field, affect radio transmission.

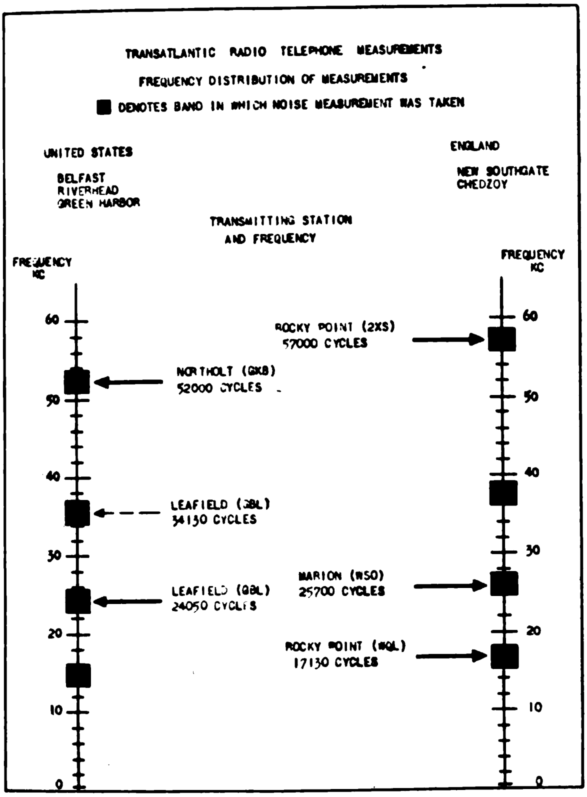


FIGURE 4

Measurement Methods

Altho it will not be necessary to describe in any detail the type of apparatus employed in making these measurements, as this information has already been published,[2] a reminder of the methods involved will facilitate an understanding of the data.

In general, the method employed in measuring the signal field strength is a comparison one. A reference radio-frequency voltage of known value is introduced in the loop antenna and adjusted to give the same receiver output as that from the distant signal. This is determined either by aural or visual means. Under such conditions equal voltages are introduced in the antenna from local and distant sources, and by calculating the effective height of the loop the field strength of the received signal is determined.

In the noise measurements, static noise is admitted thru a definite frequency band approximately 2,700 cycles wide. A local radio-frequency signal of known and adjustable voltage is then introduced. The radio-frequency source of this signal is subjected to a continual frequency, fluctuated so that the detected note has a warbling sound. This is done in order that the effect of static upon speech can be more closely simulated than by using a steady tone. The intensity of the signal is then adjusted to such a value that further decrease results in a rapid extinction. The comparison signal is then expressed in terms of an equivalent radio field strength. Thus the static noise is measured in terms of a definite reference signal with which it interferes and is expressed in microvolts per meter.

Signal Field Strength

The curves of Figure 5 are given as examples of the field strength measurements covering a single day's run. The curves have been constructed by connecting with straight lines, the datum points of measurements taken at hourly intervals. It will be evident that they portray the major fluctuations occurring thruout the day, but that they are not sufficiently continuous to disclose, in detail, the intermediate fluctuations to which the transmission is subject.

Diurnal Variation—The left-hand curve is for transmission from England to America on 52 kilocycles, and the right-hand one for transmission from America to England on 57 kilocycles. These curves illustrate the fact, which further data sub-

[2] "Radio Transmission Measurements," Bown, Englund, and Friis, Proceedings of The Institute of Radio Engineers, April, 1923.

stantiate, that both transmissions are subject to substantially the same diurnal variation. The condition of the trans-Atlantic transmission path with respect to daylight and darkness is indicated by the bands beneath the curves. The black portion indicates the time during which the trans-Atlantic path is entirely in darkness, the shaded portions the time during which it is only partially in darkness, and the unshaded portions the time during which daylight pervades the entire path.

The diurnal variation may be traced thru as follows:

1. Relatively constant field strength prevails during the daylight period.

2. A decided drop in transmission accompanies the occurrence of sunset in the transmission path between the two terminals.

3. The advent of night-time conditions causes a rapid rise in field strength to high values, which are maintained until daylight approaches.

4. The encroachment of daylight upon the eastern terminal causes a rapid drop in signal strength. This drop sometimes extends into a morning dip similar to, but smaller than, the evening dip. After this, relatively steady daylight field strengths again obtain.

Three or four curves similar to Figure 5 are obtained each month. By taking the average of such curves for the month of September, 1923, the lower curve on Figure 6 is obtained. The

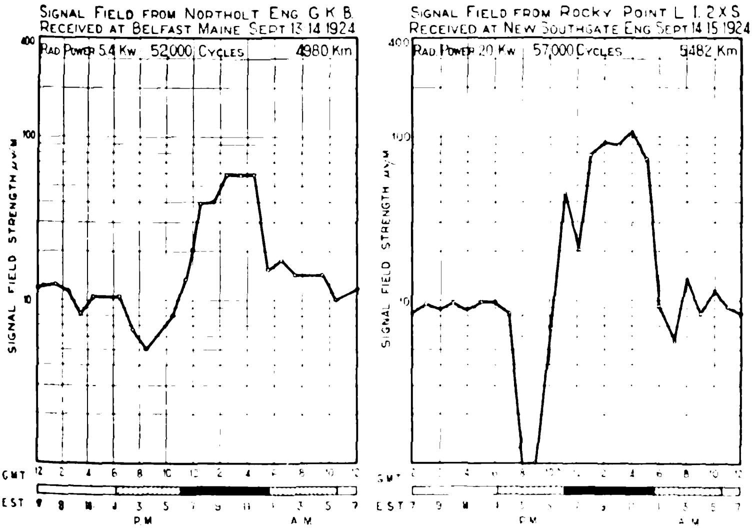


FIGURE 5—Diurnal Variation in Signal Field

upper curves are for similar averages of measurements made on the lower frequencies. These curves show clearly that the range of the diurnal fluctuation is less for the lower frequencies. This is because of the lesser daylight absorption.

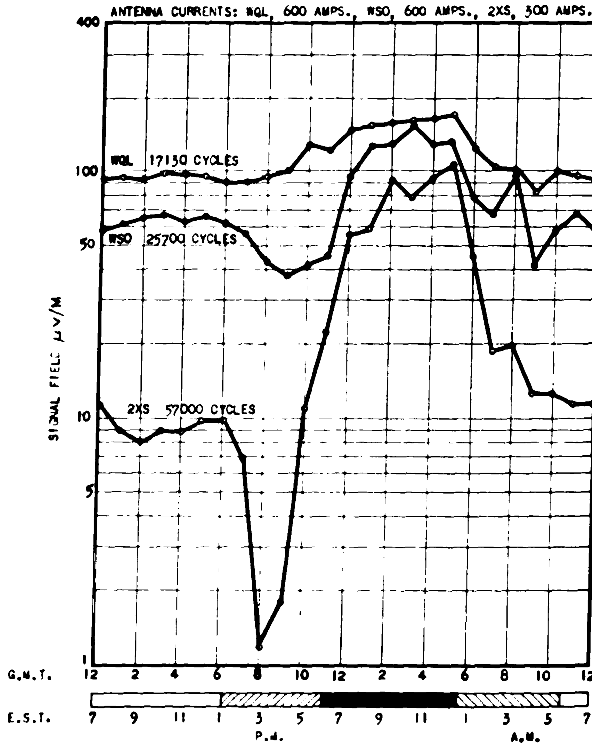


FIGURE 6—Monthly Average of Diurnal Variation in Signal Field Transmission from American Stations on Various Frequencies. Received at New Southgate, England. September, 1923

The mechanism by which the trans-Atlantic transmission path is subjected to these daily and seasonal controls on the part of the sun would be more evident were we enabled to observe the earth from a fixed point in space. We should then be able to see the North Atlantic area plunged alternately into daylight and darkness as the earth rotates upon its axis, and to visualize the seasonal variation of this exposure to sunlight as the earth revolves about the sun. Photographs of a model of the earth showing these conditions have been made, and are shown in Figure 7. The first condition is that for January, in which the entire path is in daylight. The curve of diurnal variation is shown in the

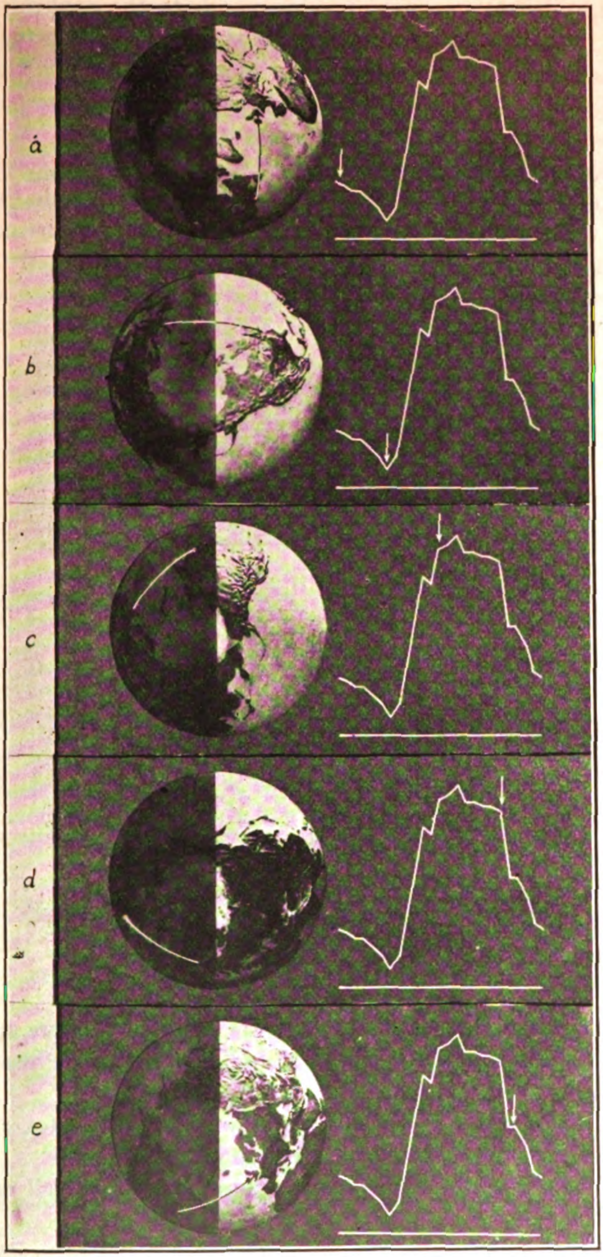


FIGURE 7—Diurnal Variation in January Signal Field. *a.* Total Path in Sunlight. *b.* Sunset Near Midpoint of Transmission Path. *c.* Sunset Conditions When High Night Values Have Been Obtained. *d.* Sunrise Conditions When High Night Values Begin to Decrease. *e.* Sunrise Near Midpoint of Transmission Path

picture and that part which corresponds to the daylight condition is indicated by the arrow. In the next position the earth has rotated so that the London terminal is in darkness while the United States terminal is still in daylight. This corresponds to the evening dip, the period of poorest transmission. With the further rotation of the earth into full night-time conditions for the entire path, the received signal rises to the high night-time values. These high values continue until the path approaches the daylight hemisphere, as indicated in the fourth position. As the path enters into sunlight, the signal strength drops with a small dip occurring when sunrise intervenes between the two terminals.

SEASONAL VARIATION—By assembling the monthly average curves for all months of the year, the effect of the seasonal variation on the diurnal characteristic becomes evident. This is shown in Figure 8, the data for which actually cover two years.

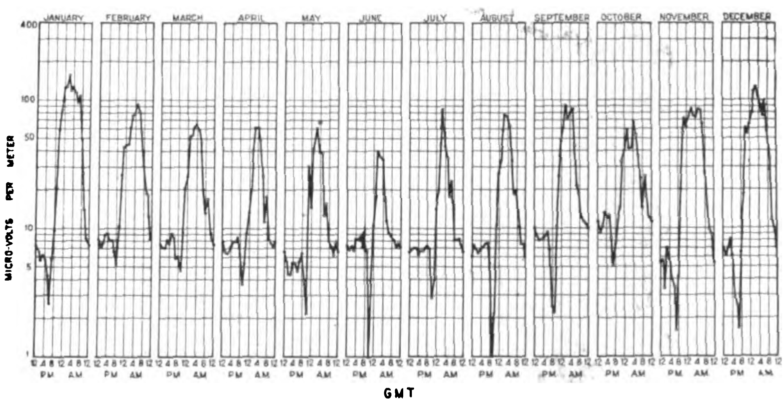


FIGURE 8—Monthly Averages of Diurnal Variation in Signal Field. Rocky Point, L. I. (2XS) To New Southgate, England. 57,000 Cycles—Antenna Current, 300 Amperes—5,480 Km.
1923—1924

The outstanding points to be observed in this figure are:

1. The continuance of the high night-time values thruout the year.

2. The persistence of the high night-time values for a longer period in the winter than in the summer months.

3. The daylight values show a comparatively small range of variation.

4. The extreme range of variation shown between the minimum of the sunset dip and the maximum of the high night-time values is of the order of 1-to-100 in field strength. This is equivalent to 1-to-10,000 in power ratio.

It will be recalled that the cause of the seasonal changes upon the earth's surface resides in the fact that the earth's axis is inclined and not perpendicular to the plane of its orbit about the sun. As the earth revolves about the sun, the sunlit hemisphere gradually extends farther and farther northward in the spring months and by the summer solstice reaches well beyond the north pole, as indicated in Figure 9. As the earth continues to revolve

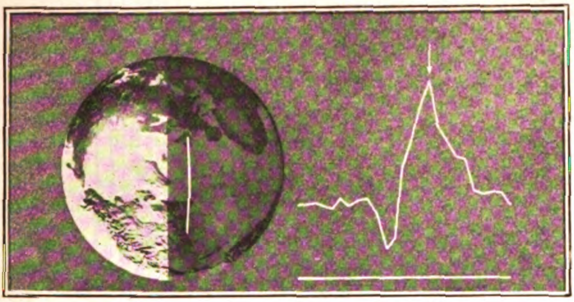


FIGURE 9—Night Conditions in June. Sunlight 170 Km. Above Great Circle Path Between New York and London

about the sun, the sunlit hemisphere recedes southward until at the winter solstice it falls considerably short of the north pole and extends correspondingly beyond the south pole. Since the trans-Atlantic path lies fairly high in the northern latitude, it is not astonishing that the transmission conditions disclose a decided seasonal influence. The effect of this seasonal influence in shifting the diurnal transmission characteristic is better shown in Figure 10. This figure consists of the same monthly average diurnal curves as are assembled in Figure 8, arranged one above the other instead of side by side.

In particular, there should be noted:

1. The time at which the sunset dip occurs changes with the change in time of sunset.

2. Similarly, the time at which the morning drop in field strength occurs changes with the time of sunrise.

3. The period of high night-time values, bounded between the time of sunset in the United States and the time of sunrise in England, is much longer in the winter than in the summer months.

It is also to be observed that, as a rule, full night-time values of signal field strength are not attained until some time after sunset at the western terminal and that they begin to decrease before sunrise at the eastern terminal. In other words, the day-

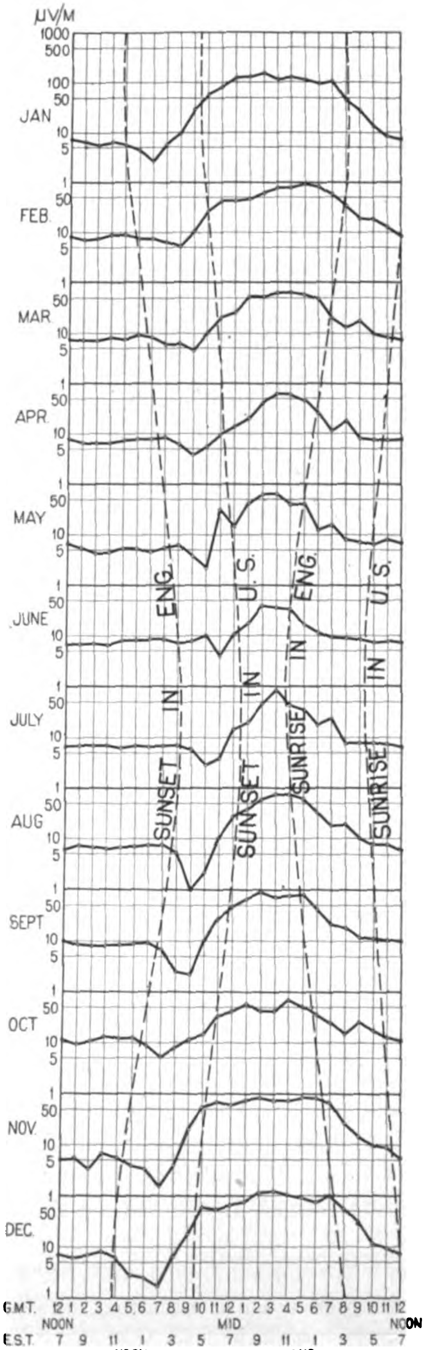


FIGURE 10—Monthly Averages of Diurnal Variation in Signal Field. Rocky Point, L. I. (2XS) Measured at New Southgate, England. 20.8 kw. radiated. 5,480 km. 57,000 Cycles
1923—1924

light effects appear to extend into the period in which the transmission path along the earth's surface is unexposed to direct rays of the sun. The effect of this is that with the advance of the season from winter to summer, the time at which the high night-time value is fully attained, occurs later and later, whereas the time at which it begins to fall off occurs earlier and earlier, until the latter part of April when these two times coincide. At this time, then, the transmission path no sooner comes into the full night-time conditions than it again emerges. As the season further advances into the summer, the day conditions begin to set in while the night-time field strength is still rising. The proximity to the daylight hemisphere, which the trans-Atlantic path reaches at night during this season of the year is illustrated in Figure 9.

As the sunlit hemisphere recedes southward after the summer solstice, a time is reached, about the middle of August, when the full night-time values are again realized. Beyond this time they are sustained for increasing periods of time. It is of interest to note that at these two times of the year, the last of April and the middle of August, direct sunlight exists over the darkened hemisphere some 500 kilometers above the great circle path.

For all of the conditions noted above, namely, sunset, sunrise, and summer approach of the transmission path to the northern boundary of the night hemisphere, the path lies in a region wherein the radiation from the sun grazes the earth's surface at the edge of the sunlit hemisphere. The transmission path also approaches this region during daylight in the winter months, as will be seen by reference to the first position of Figure 7 for the month of January. The results of measurements for the months of November, December, and January for all of the frequencies measured show definite reductions in the daylight field strengths. This reduction is evident in Figure 8 for the 57-kilocycle transmission, but shows up more strikingly in the curves of Figure 11. The effect of each of these conditions, in which the transmission path approaches the region in which the solar emanation is tangential to the earth's surface, will be observed to be that of an increase in the transmission loss. The fact that in one instance this occurs in daylight would seem to suggest, for its explanation, the presence of some factor in addition to sunlight, such as electron emission.

FIELD STRENGTH FORMULAS—The two major phases of the diurnal variation of signal field strength which lend themselves to possible predetermination are the daylight values and the

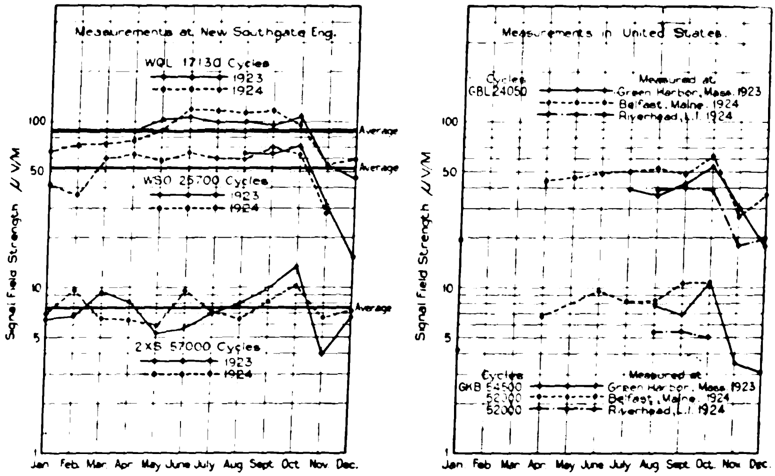


FIGURE 11—Monthly Averages of Daylight Field Strength

established night-time values. As to the night-time values our data show, within the limits of experimental error, that the maximum values do not exceed that defined by the Inverse Distance Law. This fact seems to support the viewpoint[3] that the high night-time values are merely the result of a reduction of the absorption experienced during the day. Figure 11 presents the monthly averages of the daylight field strengths for the various frequencies on which measurements were taken. The chart at the left is for reception in England and that at the right for reception in the United States.

The difficulty in predicting by transmission formulas, values to be expected at any one time will be evident and the best that can be expected is to approximate the average. The formulas of Sommerfeld, Austin-Cohen, and Fuller take the form

$$E(\mu v./m.) = \frac{377\, H\, I}{\lambda D}\, \varepsilon^{-aD}$$

where the coefficient $\frac{377\, H\, I}{\lambda D}$ represents the simple Hertzian radiation field and the exponential $\varepsilon^{-\frac{aD}{\lambda}}$ the attenuation factor. From theoretical considerations, Sommerfeld (1909) gave $a = 0.0019$ and $x = 1/3$. In the Austin-Cohen formula a is given as 0.0015 and $x = 1/2$ Fuller gives $a = 0.0045$ and $x = 1.4$. The Austin-Cohen formula was tested out experimentally chiefly

[3] See also "Radio Extension of Telephone System to Ships at Sea," Nichols and Espenschied, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, June, 1923, pages 226-227.

with data obtained from the Brant Rock station (1911) and from the Arlington station by the U. S. S. *Salem* in February and March, 1913. Fuller derived his 0.0045 value of a from 25 selected observations from tests between San Francisco and Honolulu in 1914.

An attempt has been made to determine the constants of a formula of the above form which would approximate averages of some 5,000 observed values of field strength over this particular New York to London path and over the frequency range of 17 kc. to 60 kc. For each transmitting station a series of comparatively local measurements were taken to determine the power radiated. By combining these local measurements with the values obtained on the other side of the Atlantic we found that approximately $a = 0.005$ and $x = 1.25$. The transmission formula then becomes

$$E(\mu v./m.) = \frac{377\,H\,I}{\lambda D}\,\varepsilon^{-\frac{0.005\,D}{\lambda^{1.25}}}$$

or in terms of power radiated

$$E = \sqrt{P}\,\frac{298 \times 10^3}{D}\,\varepsilon^{-\frac{0.005\,D}{\lambda^{1.25}}}$$

where

E = Field strength in microvolts per meter
P = Radiated power in kw.
D = Distance in km.
λ = Wave length in km.

Correlation Between Radio Transmission and Earth's Magnetic Field—In analyzing the measurements we were impressed by the occasional occurrence of marked deviations from the apparent normal diurnal characteristic. A series of measurements which includes an example of this condition is represented in the upper curves of Figure 12. The curves of the first four days exhibit the normal diurnal characteristic as did the curves of the preceding measurements. The next test of February 25-26 exhibits a marked contrast with that of two days previous. Such abnormality continues in greater or less degree until partial recovery in the test of April 29-30.

The table following summarizes the data relative to daylight transmission.

TRANSATLANTIC RADIO TELEPHONE MEASUREMENTS

Transmitting Terminal	Receiving Terminal	Freq.	Distance Km.	Power* Radiated Kw.	Daylight Field Strengths Observed			Daylight Field Strengths Calculated		
					1923	1924	Av.	Austin-Cohen	Fuller	This Paper
2XS	New Southgate, England	57,000	5482	20.6	7.5	7.65	7.6	6.9	21.2	7.8
WSO	New Southgate, England	25,700	5282	8.95	(Aug.-Dec.) 48.7	(Jan.-Nov.) 54.6	52.7	16.6	78.5	50.2
WQL	New Southgate, England	17,130	5482	12.	(Apr.-Dec.) 86	87.2	86.8	27.7	116.	86.
GBL	Green Harbor, Mass.	24,050	5149	4.06	(July-Jan.) 34.2			13.2	59.	39.
	Belfast, Maine	24,050	4885	4.06		(Apr.-Dec.) 51(?)		15.6	64.7	41.8
	Riverhead, L. I.	24,050	5363	4.06		(Aug.-Dec.) 31.5		11.4	55.2	34.5
GBL	Green Harbor, Mass.	34,130	5149	4.85	(July-Jan.) 16.1			9.5	41.2	22.6
GKB	Green Harbor, Mass.	54,500	5241	7.9	(Aug.-Dec.) 6.1			5.6	18.6	7.1
	Belfast, Maine	52,000	4980	5.4		(Apr.-Oct.) 9.1		6.15	20.	9.05
	Riverhead, L. I.	52,000	5457	5.4		(Aug.-Oct.) 5.3		4.2	15.	5.9

*Computed from local observations using formula of this paper.

NOTE—Measurements of transmission from Rocky Point (2XS) on 57,000 cycles measured at Mexico City, July, 1924, give an average daylight field strength of 39.4 $\mu v./m.$ Calculated value 42.5 $\mu v./m.$

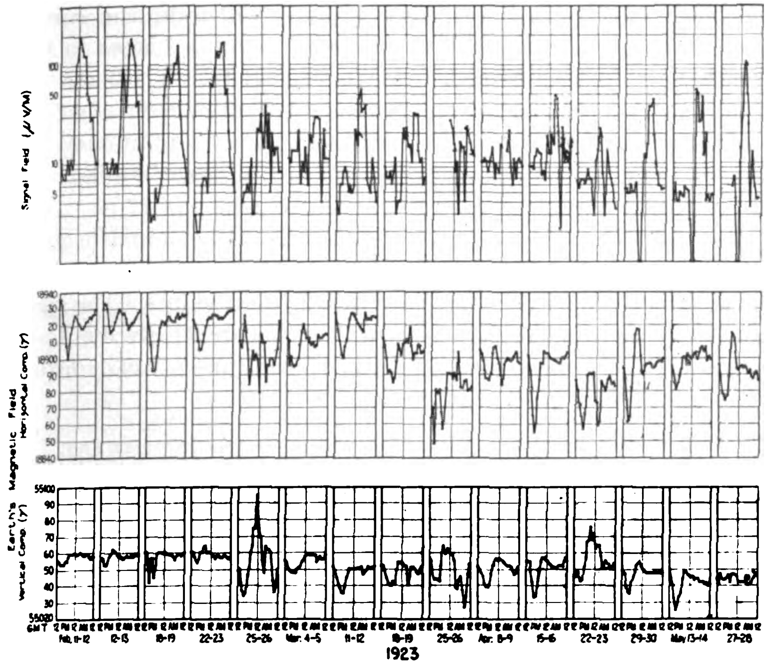


FIGURE 12—Correlation of Radio Transmission and Earth's Magnetic Field. Transmission from Rocky Point, L. I., U. S. A. (57,000 Cycles) to London, England. Earth's Magnetic Field Measured at Cheltenham, Md., U. S. A.

Comparison of these data with those of the earth's magnetic field for corresponding days shows a rather consistent correlation. This will be evident from inspection of the magnetic data plotted below the same figure. Both the horizontal and vertical components of the earth's field are shown. The first decided abnormality occurs February 25-26. The three succeeding periods show a tendency to recover followed by a second abnormality on March 25-26 and again one on April 22-23. It is of interest to note that within limitations of the intervals at which measurements were taken, these periods correspond roughly to the 27-day period of the sun. Coincidences similar to those described above have been found for other periods. Except for this coincidence of abnormal variations in earth's magnetic field and radio transmission, exact correlation of the fluctuations has not been found possible.

The magnetic data have been supplied thru the courtesy of the United States Goedetic Survey. Similar data taken in England were obtained from the Kew observatory and show similar results.

The contrast in the diurnal variations of radio transmission before and after the time a magnetic storm is known to have started, is further brought out in Figure 13. The lower left-hand curve in this figure superimposes curves of February 22-23, and February 25-26 of the previous figure. Additional cases where such marked changes occur are also shown. It will be seen that similar effects exist on the lower frequency of 17 kc. All of these examples are for days of other than maximum magnetic disturbance. In general the effect is to reduce greatly the night-time values and slightly increase the daylight values. The higher peaks in the daylight field strength of Figure 11 are due to the high daylight values which prevail at the time of these disturbances.

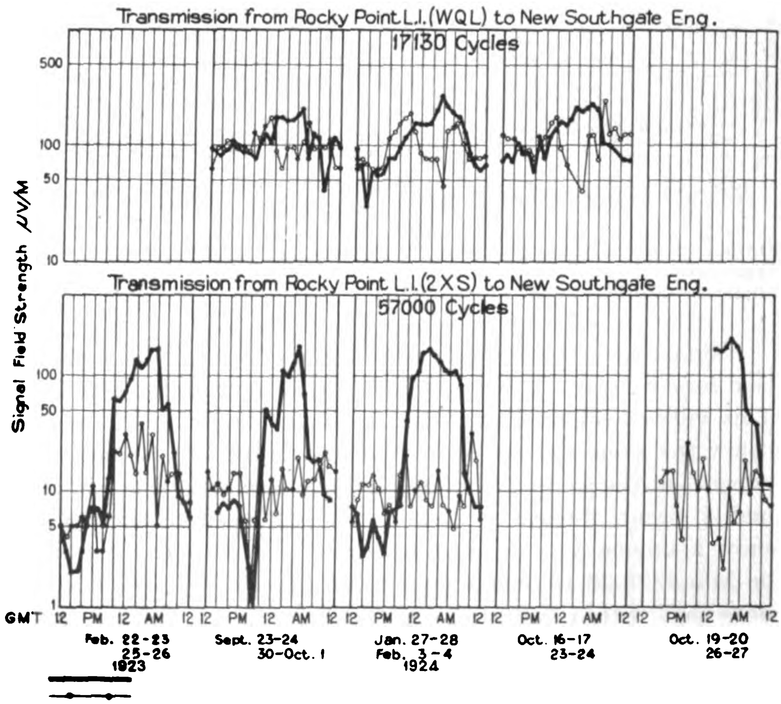


FIGURE 13—Effect of Solar Disturbances on Radio Transmission. Heavy Line Represents More or Less Normal Transmission Week End Before Disturbance Occurred. Light Line Represents Abnormal Transmission on Following Week End After Disturbance Began But Still in Progress

NOISE STRENGTH

Next to field strength the most important factor in determining the communication possibilities of a radio channel is that of the interfering noise. The extent to which noise is subject to

diurnal and seasonal vatiations is, therefore, of first order of importance.

DIURNAL VARIATION—An example of the diurnal characteristic of the noise for both ends of the trans-Atlantic path is given in Figure 14. One curve is shown for each of the several frequencies measured. The outstanding points to be observed are:

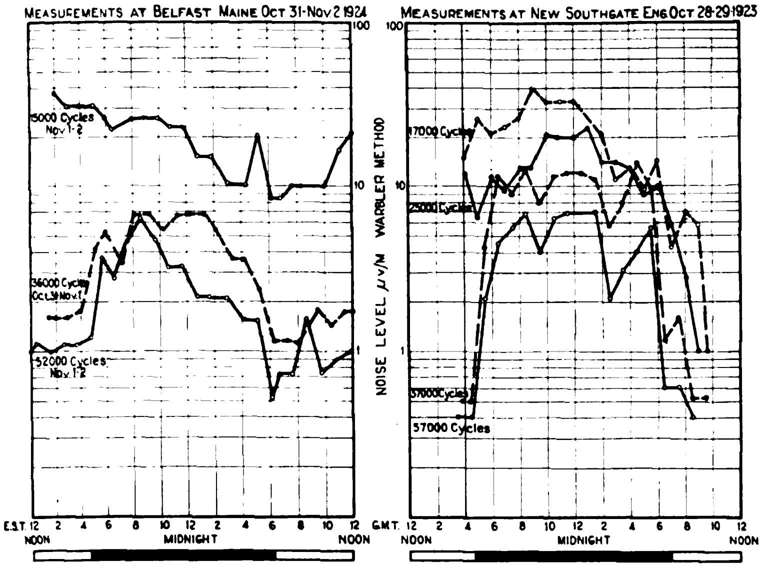


FIGURE 14—Diurnal Variation in Noise

1. The rise of the static noise about the time of sunset at the receiving station, the high values prevailing at night, and the rather sharp decreases accompanying sunrise. The curve for 15 kc. shows the existence of high values also in the afternoon period. During the summer months high afternoon values are usual for all frequencies in this range. They extend later into the Fall for the lower frequencies, and hence are in evidence on the dates on which these measurements were taken, October-November.

2. In general, the noise is greater the lower the frequency.

NOISE AS A FUNCTION OF FREQUENCY AND OF RECEIVING LOCATION—The distribution of static noise in the frequency range under consideration is depicted in Figure 15 for the case of reception at New Southgate, England. The set of full-line curves is for daylight reception and the set of dash-line curves for night-time reception. The values obtaining during the transition period between day and night have been excluded. For

both conditions three curves are shown, one the average of the summer months, another the average of winter months and the third, the heavy line, the average for the entire year. The curves represent averages for all of the measurements taken during both 1923 and 1924. In considering curves of this type it should be remembered that they represent an average of a wide range of conditions and at any one time the distribution of static may differ widely from that indicated by the curves. Also it should be realized that the extreme difference between winter and summer static is much greater than the difference between the averages.

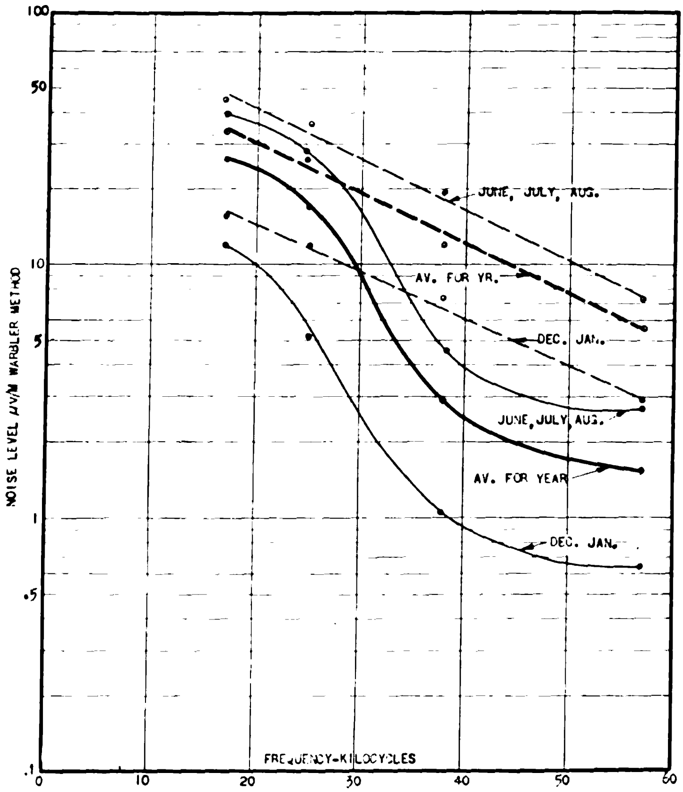


FIGURE 15—Frequency Distribution of Noise., New Southgate, England. Night-time— — — — —. Daytime————————. 1923—1924

A similar study of frequency distribution was made at two locations in the United States, Belfast and Riverhead. The results obtained at these two locations, together with those for New Southgate, England, are presented in Figure 16 for a period

during which data were obtained for all three places. The similarity of the three sets of curves shows that there is an underlying cause common to both sides of the Atlantic which may account for the difference between the daytime and night-time static on the longer waves. It will be evident from the curves that for frequencies around 20 kc. there is not very much difference between the day and night static noise, but that at the higher frequencies in the range studied, the daylight values become considerably less than the night-time values. Actually the divergence between the night-time and the daytime noise curves, up to about 40 kc., is an exponential one. This suggests that the lowering of the daylight values may be largely due to the higher absorption which occurs in the transmission medium during the day. There is a further interesting point to be noted concerning both figures, namely, that the night-time values decrease exponentially with increase in frequency. Since these night-time values are but little affected by absorption in the transmitting medium, the distribution of the static energy as received, also roughly represents the distribution of the static power generated.

The curves of Figure 16 show also the substantial difference in the noise levels which exists at the three receiving points. The New Southgate curve indicates, as has been experienced in practice, that England is less subject to interference than northeastern United States. In the United States the superiority of Belfast over Riverhead is also consistent with the better receiving results which in general have been experienced in Maine. There should be noted also the fact that the curves for these three locations lie one above the other in the inverse order of the latitudes. This is in keeping with other evidence which points towards the tropical belt as being a general center of static disturbance on the longer wave lengths. Further evidence on this point is presented below in connection with the seasonal variations of noise.

Seasonal Variation—Curves showing the diurnal variation in noise level for each month of the year as well as the variations of sunset and of sunrise are shown in Figure 17. Each curve is the average of all the measurements taken during that particular month in 1923 and 1924. The diurnal variations are generally similar for the different months in respect to the high night-time values which are limited to the period between the times of sunset and sunrise in England. There is a certain deviation, however, which it is well to point out. During the summer months the rise in night-time static starts several hours before and reaches high values at about sunset in England, whereas in the winter-

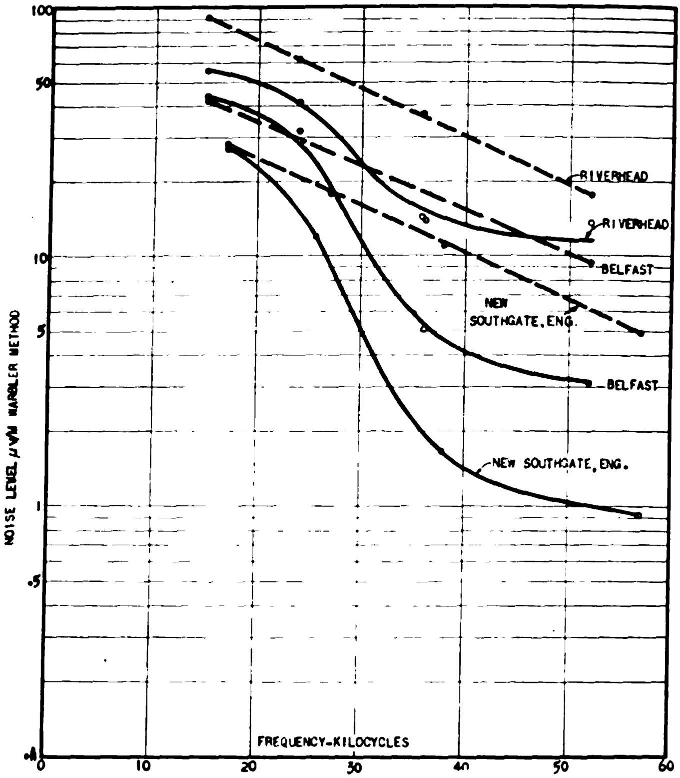


FIGURE 16—Frequency Distribution of Noise. New Southgate, England, Belfast, Maine, Riverhead, L. I. Night-time — — —. Day-time————————. August-December, 1924

time, the night-time static begins to rise at about sunset and reaches high values several hours later. A similar effect is observed for the sunrise condition wherein the reduction of static sets in during the summer months about the time of sunrise, reaches low daylight values several hours later, and in the winter the reduction commences several hours before sunrise and reaches low daylight values at sunrise. In other words, the rise to high night-time values occurs earlier with respect to sunset in the summer than in the winter, and conversely the fall from high night-time static to the lower daylight values occurs later with respect to sunrise in the summer than in the winter.

This is more definitely brought out in Figure 18, which combines the data for all frequencies measured. The dash lines associated with the sunset curves delineate the beginning and the attainment of the night-time increases, and those associated with the sunrise curve delineate the beginning and the attainment of

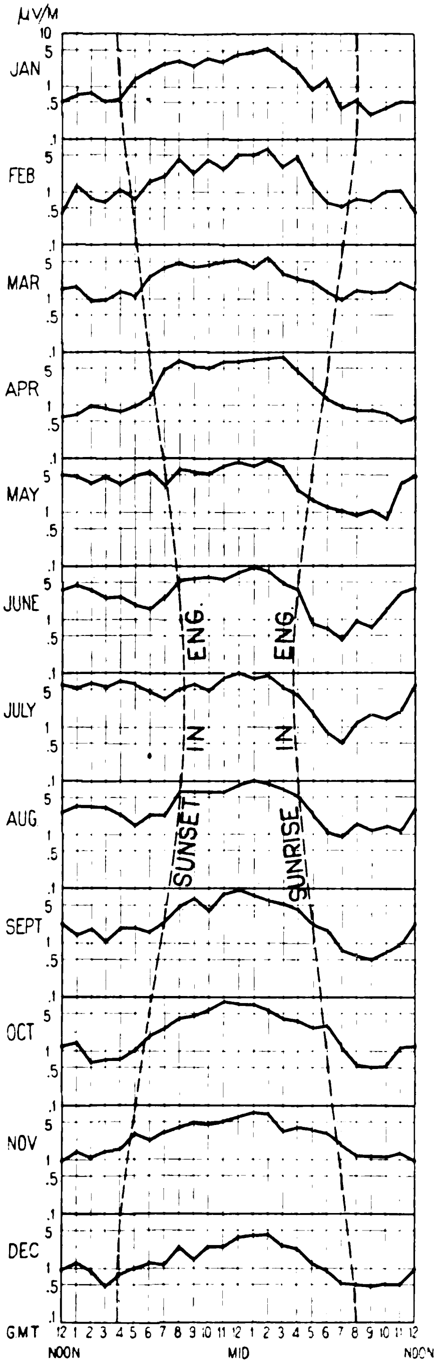


FIGURE 17—Monthly Averages of Diurnal Variation in Noise. 57,000 Cycles. New Southgate, England 1923—1924

the low daylight values. This discloses the fact that sunset and sunrise at the receiving point does not completely control the rise and fall of the high night-time static. It has been found that the discrepancy can be accounted for if sunrise and sunset are taken with respect to a static transmission path as distinguished from the receiving point alone, and if the assumption is made that the effect of sunlight upon the static transmission path is similar to that on usual radio transmission.

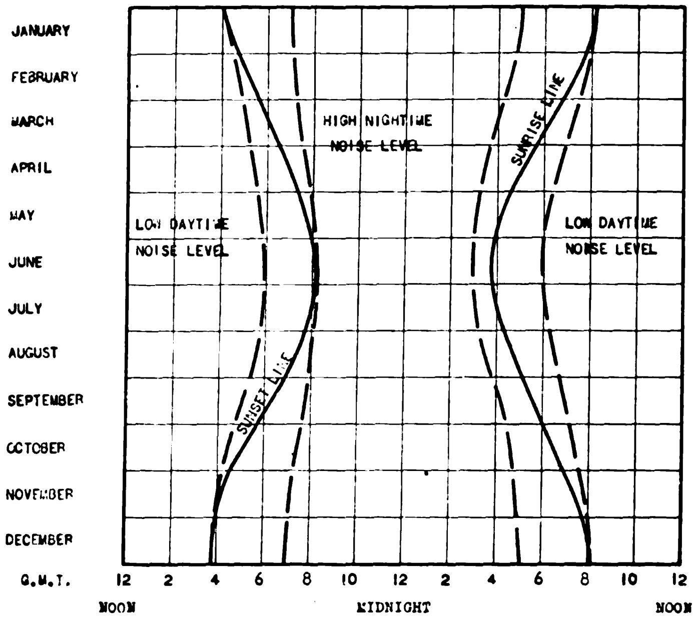


FIGURE 18—Seasonal Variation in Distribution of Daytime and Night-time Noise with Respect to Sunset and Sunrise. New Southgate, England
1923—1924

MAJOR REGIONAL SOURCE OF STATIC NOISE—A broader conception as to the causes underlying the diurnal and seasonal variations is obtained by considering the time of sunset and sunrise over a considerable area of the earth's surface. Figure 19 shows a series of day and night conditions for three representative parts of the January diurnal noise characteristic at England. It will be seen that the rise to high night values does not begin until practically the time of sunset in England with over half of Africa still in daylight. By the time the high night-time values are reached, as indicated in the second phase, darkness has pervaded all of the equatorial belt to the south of England.

Incidentally at this time sunset occurs between the United States and England, resulting in very poor signal transmission. The third phase of this series shows the noise having just reached the low daytime value and, altho the sun is just rising in England, the African equatorial belt is in sunlight, subjecting the static transmission path to high daylight atenuation.

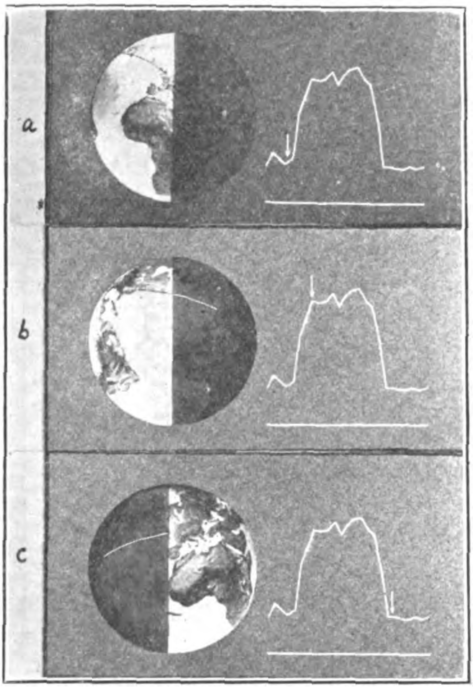


FIGURE 19—January Noise. *a.* Sunset Conditions as Night-time Noise Begins to Increase. *b.* Sunset Conditions When Noise Has Reached High Night-time Values. *c.* Sunrise Conditions When Noise Has Reached Normal Low Values

The sunset conditions which existed for the afternoon and evening of the day upon which the diurnal measurements of Figure 14 were taken are shown in Figure 20. The hourly positions of the sunset line are shown in relation to the evening rise of static in London. The coincidence between the arrival of sunset in London and the start of the high night-time noise on the higher frequencies is evident. By the time the high night-time values are reached, about 7 o'clock G. M. T., the equatorial belt to the south of London is in darkness.

Figure 21 shows the sunrise conditions in relation to the decrease in static from the high night-time values to the lower day-

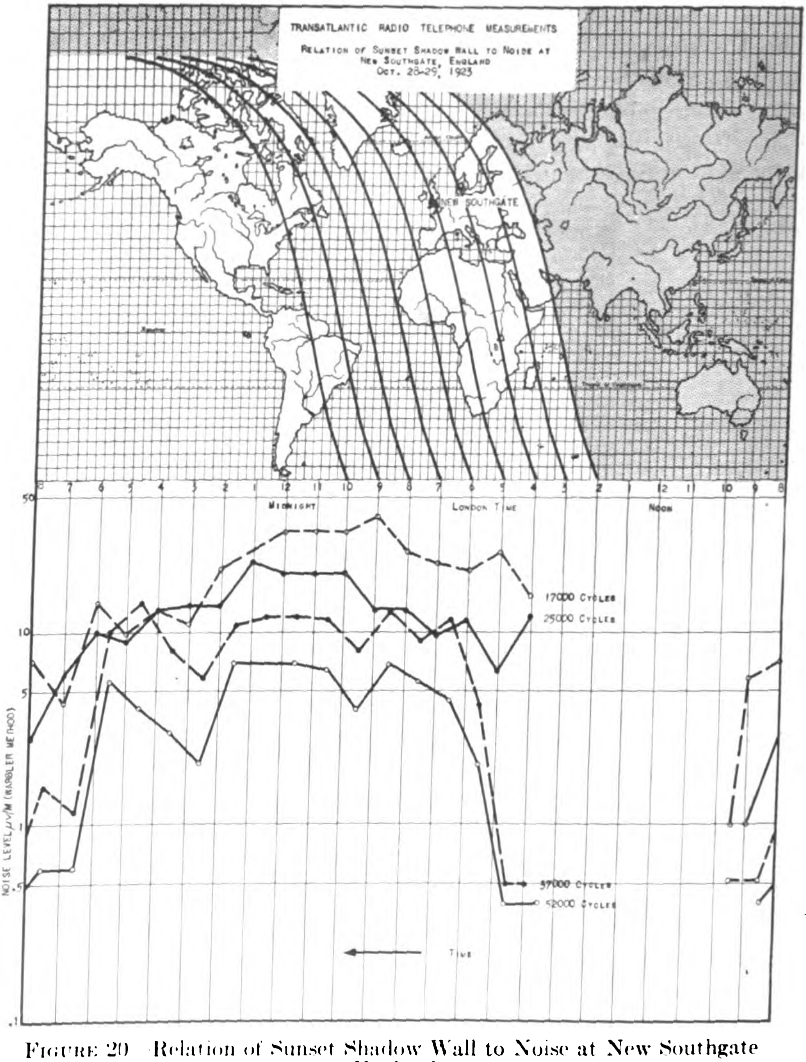


FIGURE 20 Relation of Sunset Shadow Wall to Noise at New Southgate England
October 28-29, 1923

light values. The decline starts about 5 or 6 o'clock, an hour or two before sunrise, and is not completed until several hours later, at which time daylight has extended over practically the entire tropical belt to the south of England which corresponds in general to equatorial Africa.

Another fact, presented in the previous figures, which appears to be significant in shedding light upon the source of static, is that noise on the lower frequencies rises earlier in the afternoon

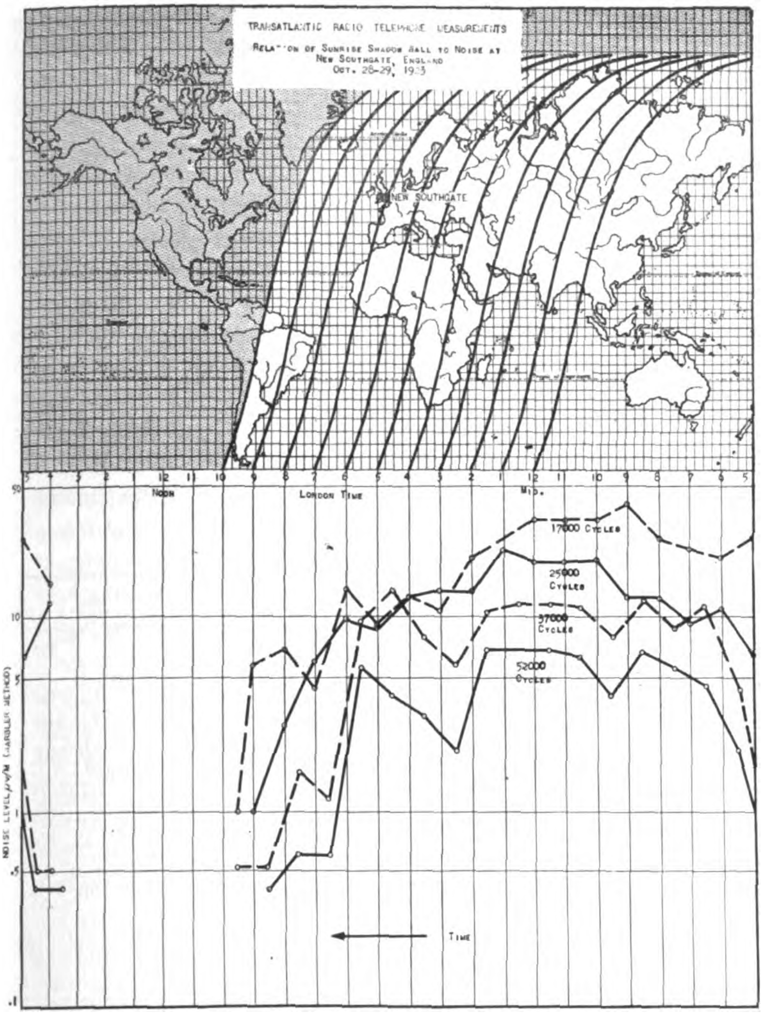


FIGURE 21—Relation of Sunrise Shadow Wall to Noise at New Southgate England
October 28-29, 1923

and persists later into the morning than does the noise on the higher frequencies. This could be accounted for on the basis that the limits of the area from which the received longer wave static originates extend farther along the equatorial zone than they do for the higher frequencies.

The inclination of the shadow line on the earth's surface, which is indicated in the previous figure for October 28, shifts to a maximum at the winter solstice, recedes to a vertical posi-

tion at the equinox and then inclines in the opposite direction. These several positions are illustrated in Figure 22. The set of three full lines to the right shows the position which the sunset shadow line assumes upon the earth's surface for each of three seasons—winter solstice, equinox, and summer solstice. Likewise, the dash-line curves show the position assumed by the sunrise line for the corresponding seasons. The particular time of day for which each of the sunset curves is taken, is that at which the static in London begins to increase to large night values. In winter, this occurs about sunset, at the equinox about one hour earlier, and in summer about two hours earlier, as illustrated in Figure 18. Correspondingly, the time for which each of the sunrise curves is taken, is that at which the high night-time values have reached the lower daylight values. From Figure 18 it will be evident that this occurs during the winter at about sunrise, at the equinox about an hour later, and during the summer some two hours later.

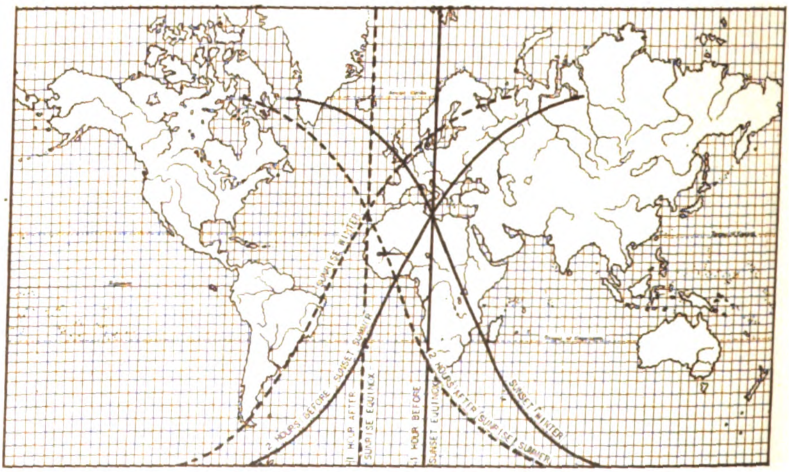


FIGURE 22—Position of Sunset Lines at Sunset Dip and Sunrise Lines at Sunrise Dip in Noise Level in England for Various Seasons

It will be observed that the two sets of curves, one for sunset and the other for sunrise, intersect at approximately the same latitude, the sunset curves southeast and the sunrise curves southwest of England. If it is assumed that the effect of the shadow wall upon the transmission of static is similar to that upon signal transmission across the Atlantic, namely, the high night-time values commence when the shadow wall is approximately half-way between the terminals, the crossing of the lines

upon the chart may be taken as having significance in roughly determining the limits of the tropical area from which the major static originates. The crossing of the sunset lines indicates that the eastern limit of the area which contributes most of the static to England is equatorial East Africa. The crossing of the sunrise lines indicates that the corresponding western limit is somewhere in the South Atlantic, between Africa and South America. In other words, from these data the indications are that there is a more or less distinct center of gravity of static, which extends along the tropical belt, and that most of the long-wave static which affects reception in England comes from the equatorial region to the south of England, namely, equatorial Africa. This is exclusive of the high afternoon static prevailing during the Summer months.

The data obtained in the United States indicate that generally similar conditions exist there as to the relation between sunset and sunrise path and the major rise and fall of static. This relationship is shown in Figure 23, which shows in the upper half the course of the night-time belt as it proceeds from Europe to America and the corresponding rise in the static noise. The noise curves are the same as those shown in Figure 14 for reception at Belfast, Maine. The rise commences about one hour before and continues for one hour or so after sundown. This is for the fall season of the year. A similar chart for the sunrise conditions is given in Figure 24. Altho high night-time values started to fall off some five hours before sundown in Belfast, the more rapid drop was within two hours in advance. While these curves are for but a single day, they are fairly representative of the average of a greater amount of data. The change in the inclination of the sunset-sunrise curves with the season of the year effects changes for American reception somewhat similar to those shown for reception in England, except that for the summer months the coincidence is less definite. It may be that this is because of the somewhat lower latitude of the United States terminal and of the reception of a greater proportion of the static from the North American continent.

In general, therefore, the American results accord with those obtained in England in indicating quite definitely that a large proportion of the static received on the longer waves is of tropical origin.

Signal-to-Noise Ratio

It is, of course, the ratio of the signal-to-noise strength which

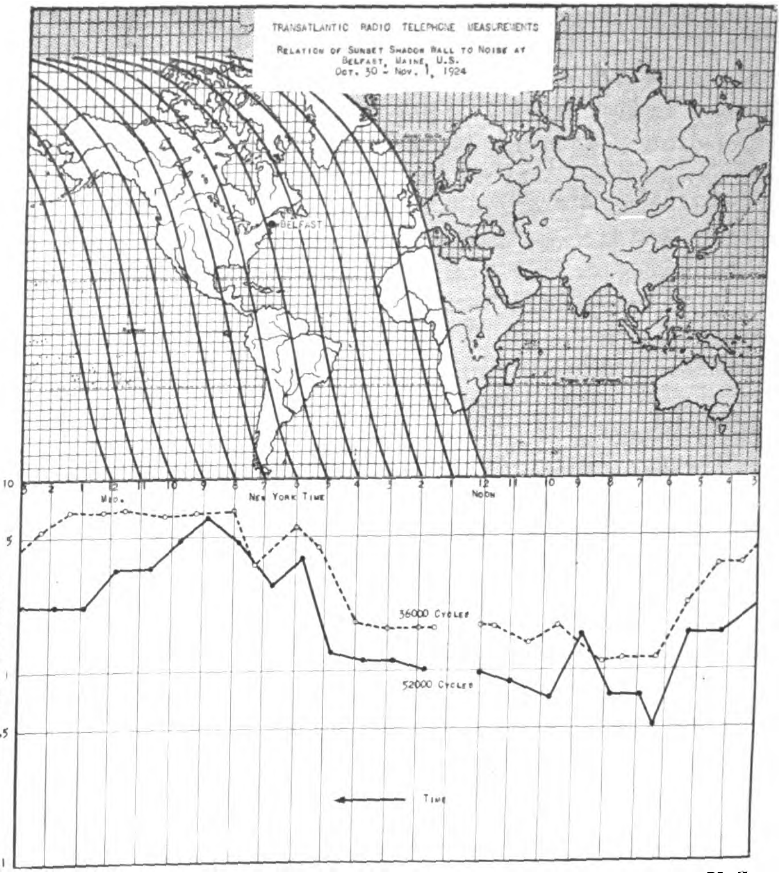


FIGURE 23—Relation of Sunset Shadow Wall to Noise at Belfast, Maine, U. S. October 30–November 1, 1924

determines the communication merit of a radio transmission channel.

VARIATION WITH FREQUENCY—Comparison of the signal-to-noise ratio for the two extreme frequencies measured, for representative summer and winter months, is given in Figure 25. Both of these transmissions were effected from the same station, Rocky Point, and similar antennas were employed. Comparison is made of the over-all transmission by correcting the values of the two curves to the same antenna power input, the power of both channels being scaled down to 68 kilowatts, the power used in the telephone channel during the early parts of the experiment. This chart shows clearly the greater stability in signal-to-noise ratio obtainable on the lower frequency channel. While for certain periods of the day the higher frequency gives a much

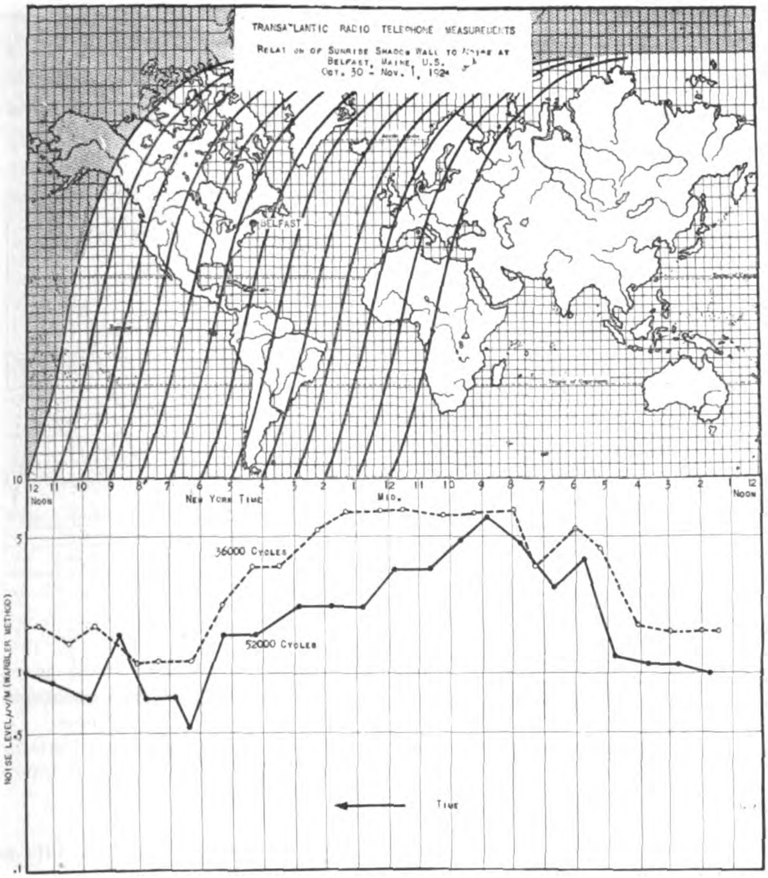


FIGURE 24—Relation of Sunrise Shadow Wall to Noise at Belfast, Maine, U. S. October 30,—November 1, 1924

better ratio, it is subject to a much more severe sunset decline than is the lower frequency. During the summer time, afternoon reception in England is better on the higher frequency channel. This is because of the considerably greater static experienced at this time on the lower frequency. The higher signal-to-noise ratio prevailing during the winter month of January as compared with the summer month of July is evident. This is due primarily to higher summer static.

SEASONAL VARIATION IN ENGLAND AND UNITED STATES—For the 57-kilocycle channel there is shown for each month of the year in Figure 26 signal-to-noise ratios of two years' data. These show a distinct dip corresponding to the sunset dip of the signal field strength. The night-time values are generally high in ac-

cordance with the high night-time signal strength, but the maximum values are shifted toward the time of sunrise. This is due to the fact that the noise rises earlier in the afternoon and declines earlier in the morning than do the corresponding variations in signal strength.

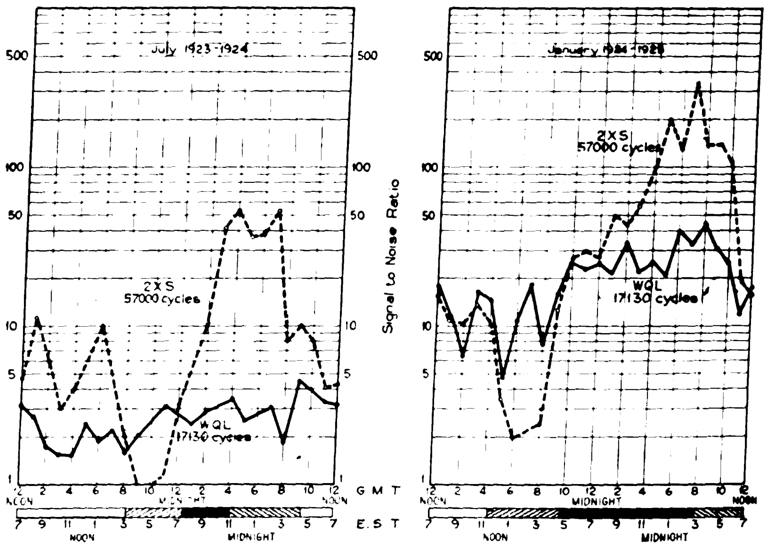


FIGURE 25—Variation of Signal-to-Noise Ratio with Frequency. Corrected to Same Antenna Input Power (68.5 kw.) in Rocky Point Antenna. Reception at New Southgate, England

Figure 27 presents the signal-to-noise ratios for such data as ave thus far been obtained upon transmission from England to the United States on a frequency of 52 kilocycles. The low values obtained about sunset are, of course, due to the evening dip in field strength. In general, the night-time ratios do not reach such high values as do those for England because the early morning signal field strength begins to fall off while the noise level is still high. Comparison of the signal-to-noise ratios obtained at New Southgate and at Belfast show that the Belfast values are somewhat higher for that part of the day which corresponds to forenoon in the United States and afternoon in England. This is because the forenoon static in the United States is lower than the afternoon static in England.

DIRECTIVE RECEIVING ANTENNAS

The picture which has been given of the transmission of static northward from the tropical belt suggests that the signal-to-

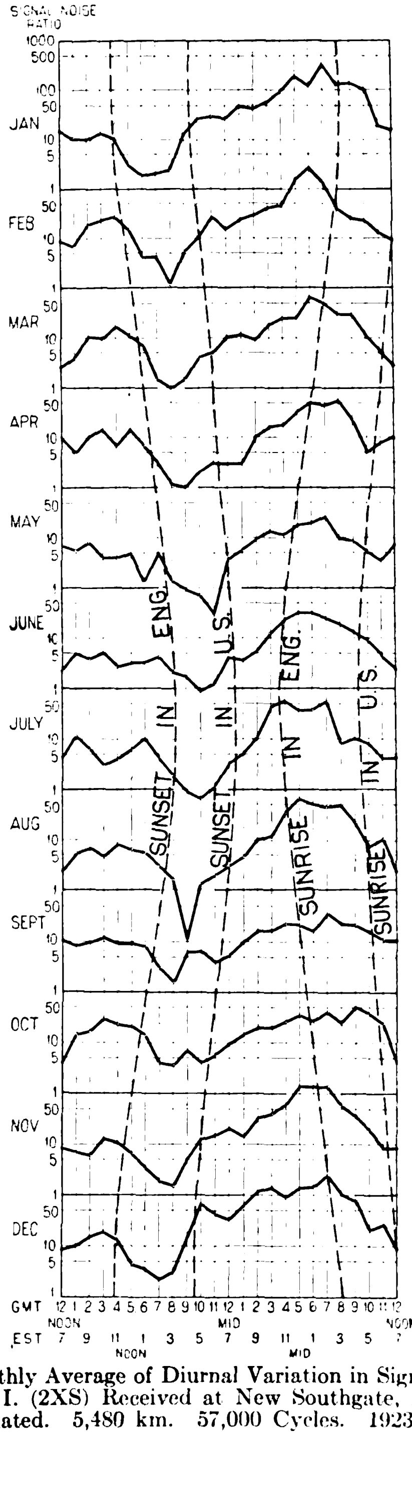


Figure 26—Monthly Average of Diurnal Variation in Signal-to-Noise Ratio. Rocky Point, L. I. (2XS) Received at New Southgate, England, 20.8 kw. radiated. 5,480 km. 57,000 Cycles. 1923-1924

noise ratio might be materially improved by the use of directional receiving systems This is, of course, what has actually been found to be the case in commercial trans-Atlantic radio telegraphy wherein the Radio Corporation of America has made such effective use of the wave antenna devised by Beverage. The expectations are confirmed by measurements which have been made in the present experiments using such wave antennas.

A year and a half ago the British Post Office established a wave antenna with which to receive from the Rocky Point radio telephone transmitter. More recently a program of consistent observations in directional reception of east-to-west transmission was also undertaken in which were employed wave antennas built by the Radio Corporation of America for radio telegraph operation upon lower frequencies.

An indication of the improvement which the wave antenna gives in signal-to-noise ratio is had by reference to Figure 28. The set of curves to the right is for reception at Chedzoy, England, and those at the left for reception at Belfast and Riverhead in the United States. The improvement is measured in terms of the signal-to-noise ratio obtained on the wave antenna, divided by the signal-to-noise ratio measured on the loop. For the particular days and frequency indicated, the improvement in England will be seen to vary over a considerable range, averaging about 5. Data for reception in England are for 1924, while those for the United States are for the corresponding period of 1925. The United States results will be seen to be generally similar to those obtained in England. Altho these experiments are still in an early stage, the results do give a measure of the order of improvement which can be expected.

Test of Words Understood—Perhaps the most convincing measure of the efficiency of directional receiving systems for trans-Atlantic transmission is the improvement effected in the reception of intelligible words. Figure 29 shows the improvement which the wave antenna in England has made in the ability to receive certain test words spoken from Rocky Point. For this purpose there was transmitted from Rocky Point a list of disconnected words. A record was made at Chedzoy of the percentage of the words understood for reception on the loop and on the wave antenna. This constitutes a convenient method of rough telephone testing. It will be appreciated, however, that it would be possible to understand a greater proportion of a conversation than is represented by these results. The curves show that it was possible to receive, for example, 80 percent of the

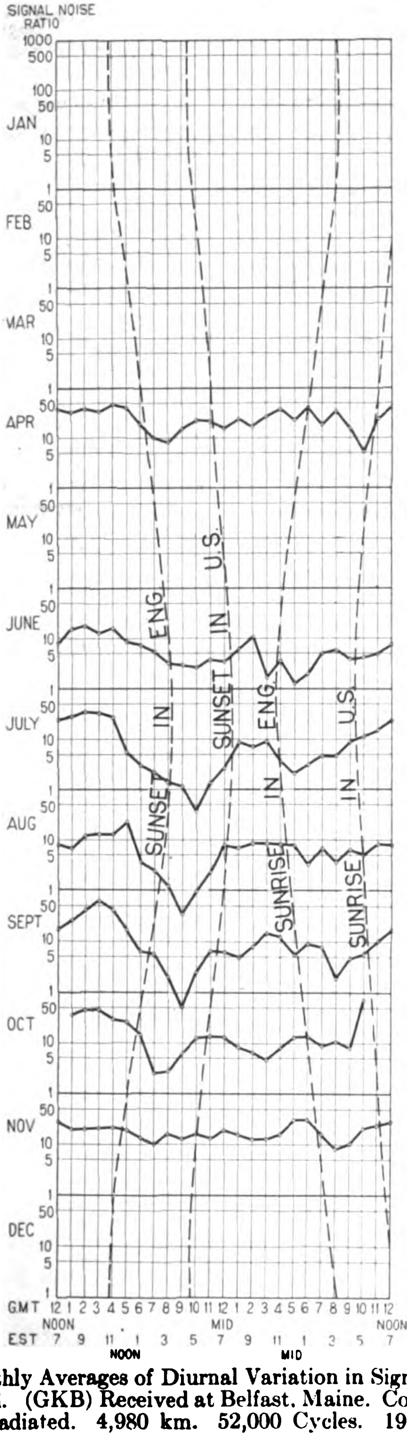


FIGURE 27—Monthly Averages of Diurnal Variation in Signal-to-Noise Ratio. Northolt, England. (GKB) Received at Belfast, Maine. Corrected to 20,8 kw. Radiated. 4,980 km. 52,000 Cycles. 1924

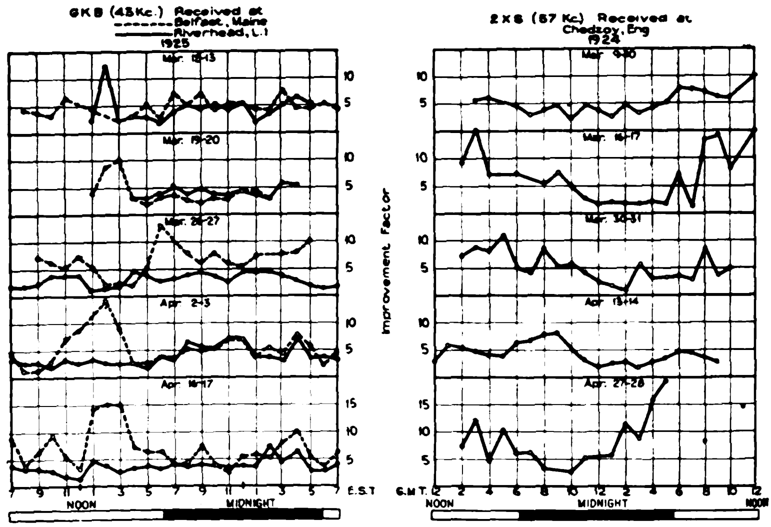


FIGURE 28—Improvement in Signal-Noise Ratio of Wave Antenna Over Loop Reception

words for but 9 of the 24 hours on the loop, whereas with the wave antenna, reception continued for 18 hours.

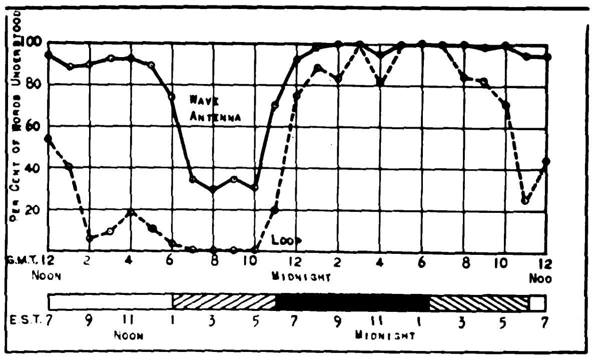


FIGURE 29—Comparison of Reception on Wave Antenna and Loop Percent of Words Understood. Reception of Rocky Point (2XS) at Chedzoy, England, March, 1924

CONCLUSIONS: This paper gives analyses of observations of long-wave transmission across the Atlantic over a period of about two years. The principal conclusions which the data seem to justify are as follows:

1. Solar radiation is the controlling factor in determining the diurnal and seasonal variations in signal field. Transmission

from east to west and west to east exhibit similar characteristics

2. Transmission in the region bordering on the division between the illuminated and the darkened hemispheres is characterized by increased attenuation. This manifests itself in the sunset and sunrise dips, the decrease in the persistence of high night-time values in summer, and the decrease in daylight values during the winter.

3. Definite correlation has been found between abnormal radio transmission and disturbances in the earth's magnetic field. The effect is to decrease greatly the night-time field strength and to increase slightly the daylight values.

4. The limit of the high night-time value of signal field strength for trans-Atlantic distance is essentially that given by the Inverse Distance Law. The normal daylight field strengths obtained in these tests can be approximated by a formula of the same form as those earlier proposed but with somewhat different constants.

5 The major source of long-wave static, as received in both England and the United States, is indicated to be of tropical origin.

6. In general, the static noise is lower at the higher frequencies. At night the decrease with increase in frequency is exponential. In daytime the decrease with increase in frequency is linear in range of 15 to 40 kilocycles. The difference between day and night static is, therefore, apparently due largely to daylight attenuation.

7. The effect of the static noise in interfering with signal transmission, as shown by the diurnal variations in the signal-to-noise ratio, is found to be generally similar on both sides of the Atlantic.

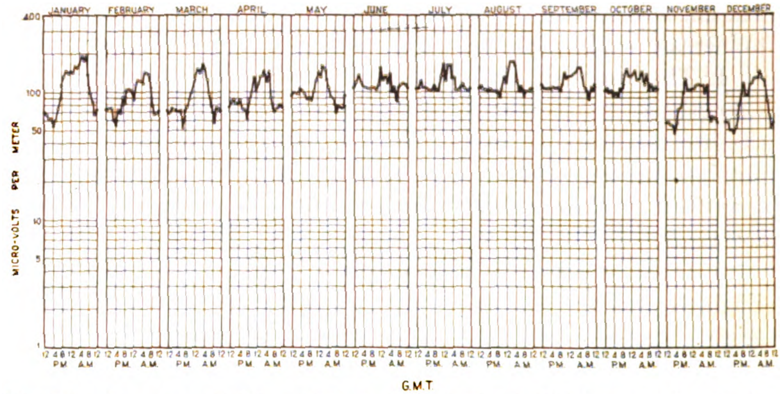
8. Experiments in both the United States and England with directional receiving antennas of the wave antenna type show an average improvement in the signal-to-static ratio of about 5 as compared with loop reception.

SUMMARY: The paper reports upon measurements of trans-Atlantic radio transmission which had been made during the past two years in a study of the possibilities of trans-Atlantic radio telephony. These measurements cover several different frequencies in the range below 60 kilocycles in both directions across the Atlantic and represent probably the most comprehensive study yet made of any transmission path. An earlier paper described the special high-power radio telephone system and the measurement methods employed in the tests, and gave certain preliminary measurement results.

The relation which exists between the diurnal and seasonal variations of signal field and the exposure of the transmission path to sunlight is shown. The conformity of the measured results to the values determined by formulas is indicated. Interesting correlation is shown between abnormal radio transmission and magnetic storms.

The diurnal and seasonal characteristics of noise are shown to be generally similar to those of signal strength and indicate the noise to be of tropical origin. The average frequency distribution of static is shown for various receiving stations.

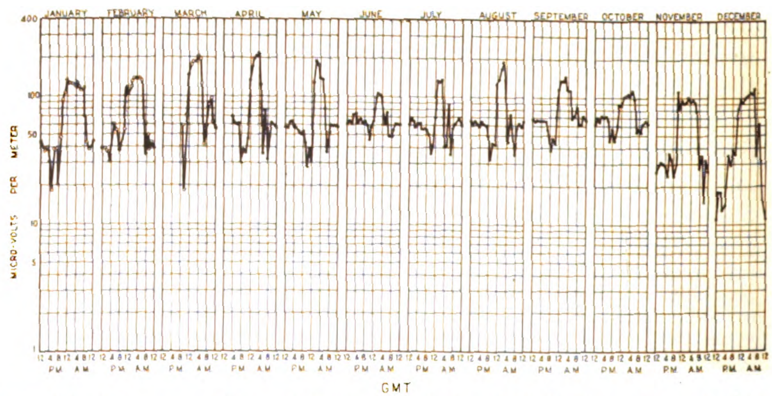
Signal-to-noise ratios are shown for both England and United States for transmission on 50 odd kilocycles, together with the improvement afforded by a directional receiving system of the wave-antenna type.



Monthly Averages of Diurnal Variation of Signal Field Strength. Rocky Point, L. I., U. S. A. (WQL) Measured at New Southgate, England. Corrected to 600 Amperes Antenna Current

5,480 Km. 17,130 Cycles

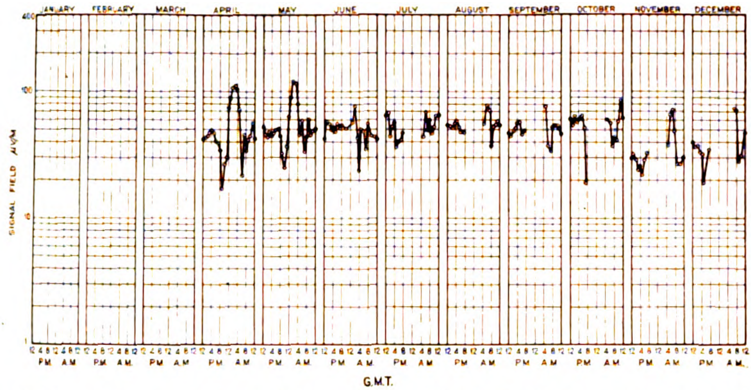
April, 1923—February, 1925



Monthly Averages of Diurnal Variation of Signal Field Strength. Marion, Mass., U. S. A. (WSO) Measured at New Southgate, England. Corrected to 600 Amperes Antenna Current

5,280 Km. 25,700 Cycles

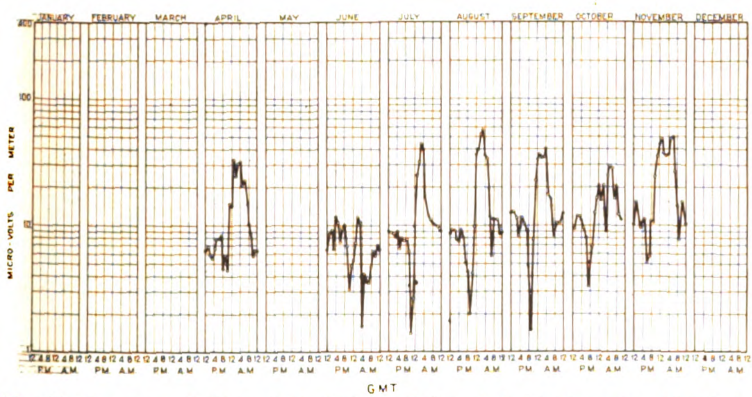
August, 1923—February, 1925



Monthly Averages of Diurnal Variation of Signal Field Strength. Leafield England. (GBL) Measured at Belfast, Maine. Corrected to 300 Amperes Antenna Current

4,980 Km. 24,050 Cycles

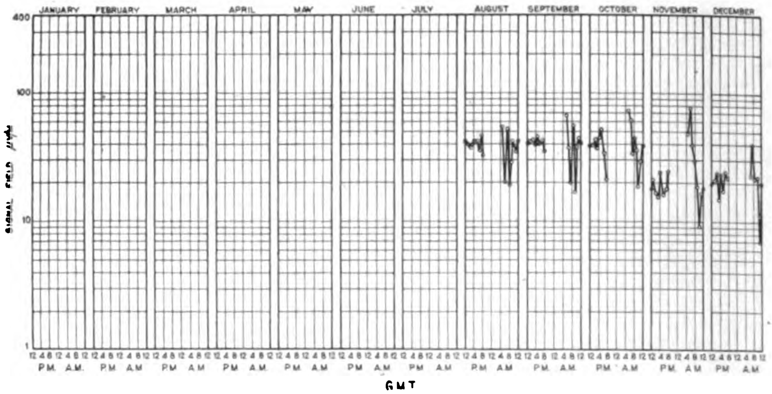
1924



Monthly Averages of Diurnal Variations of Signal Field Strength. Northolt, England. (GKB) Measured at Belfast, Maine. Corrected to 100 Amperes Antenna Current

4,885 Km. 52,000 Cycles

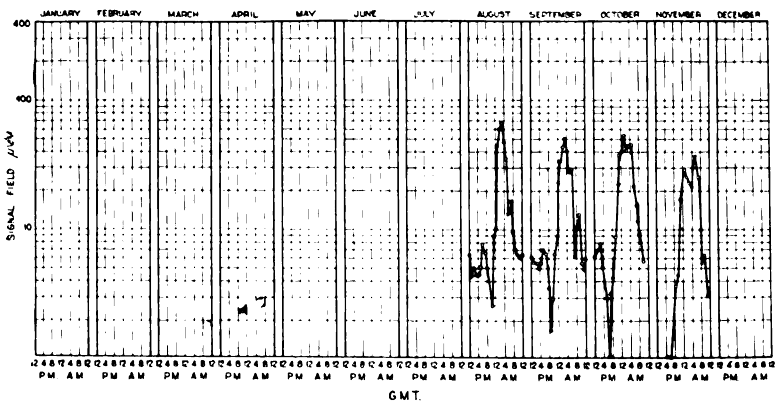
1924



Monthly Averages of Diurnal Variation of Signal Field Strength. Leafield, England (GBL) Measured at Riverhead, L. I. Corrected to 300 Amperes Antenna Current.

5,360 Km. 24,050 Cycles

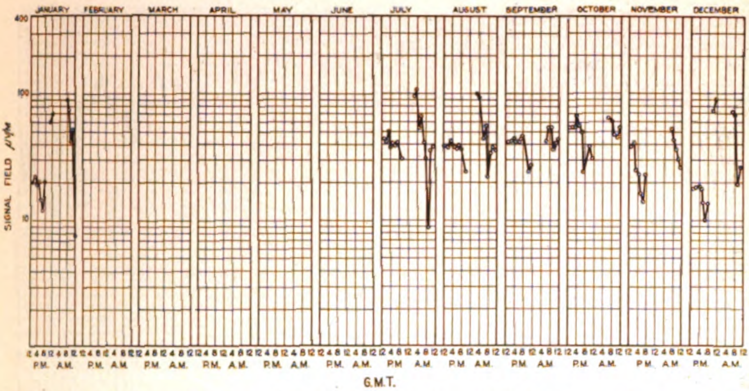
1924



Monthly Averages of Diurnal Variation of Signal Field Strength. Northolt, England. (GKB) Measured at Riverhead, L. I., Corrected to 100 Amperes Antenna Current

5,460 Km. 52,000 Cycles

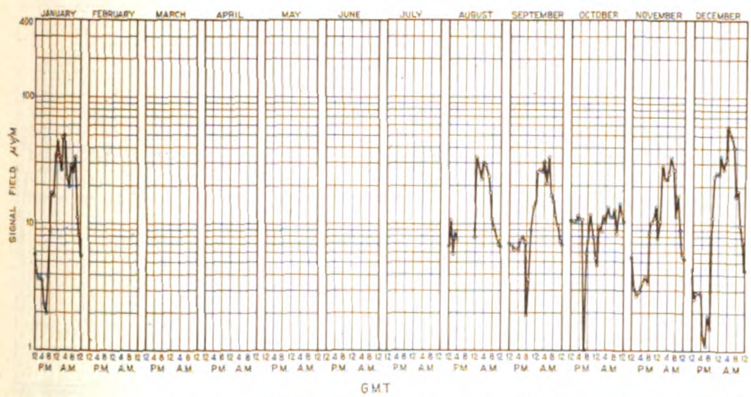
1924



Monthly Averages of Diurnal Variation of Signal Field Strength. Leafield, England. (GBL) Measured at Green Harbor, Mass. Corrected to 300 Amperes Antenna Current

5,150 Km. 24,050 Cycles

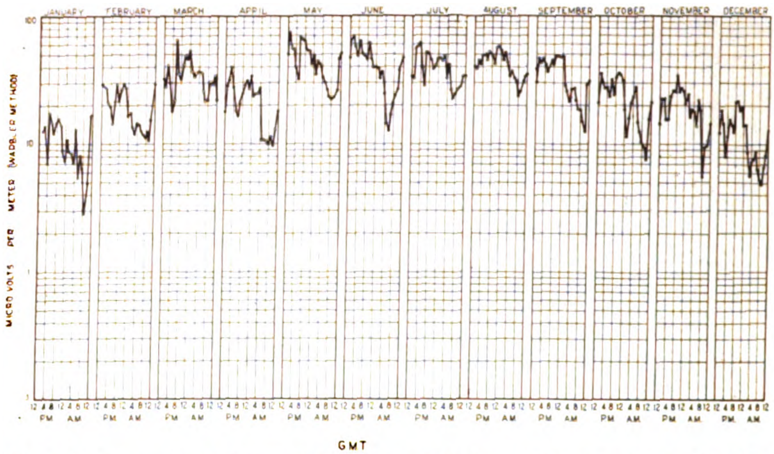
July, 1923—January, 1924



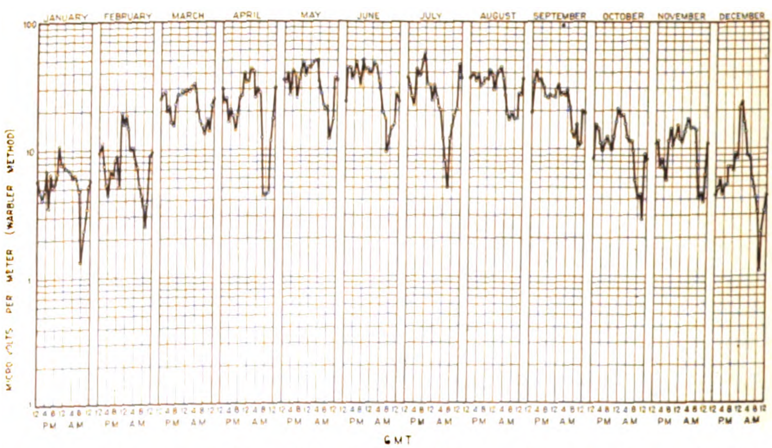
Monthly Averages of Diurnal Variation of Signal Field Strength. Northolt, England. (GKB) Measured at Green Harbor, Mass. Corrected to 100 Amperes Antenna Current

5,240 Km. 54,500 Cycles

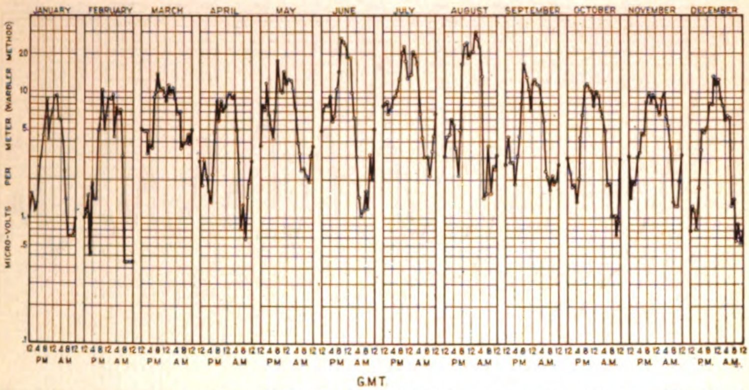
August, 1923—January, 1924



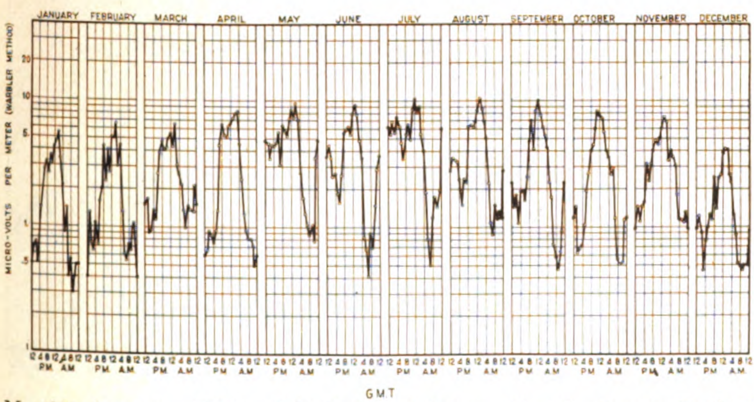
Monthly Averages of Diurnal Variation of Noise. New Southgate, England
17,000 Cycles
April, 1923—February, 1925



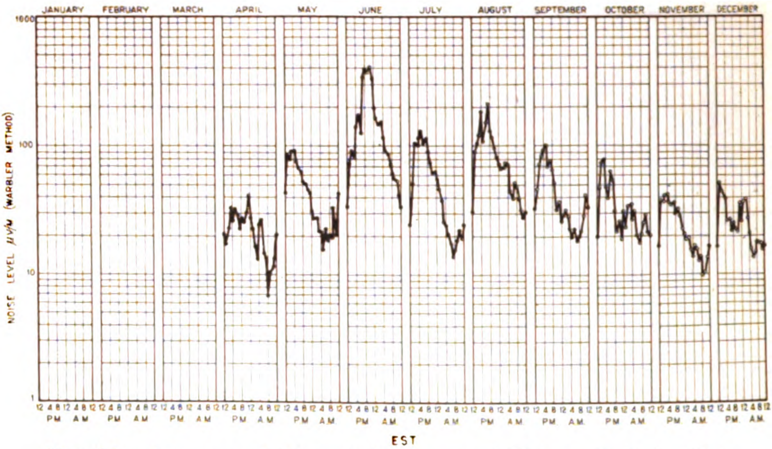
Monthly Averages of Diurnal Variation of Noise. New Southgate, England
25,000 Cycles
August, 1923—February, 1925



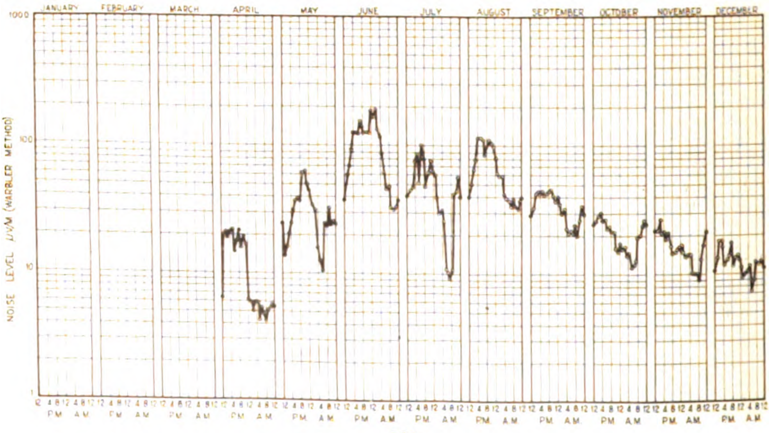
Monthly Averages of Diurnal Variation of Noise. New Southgate, England
37,000 Cycles
October, 1923—February, 1925



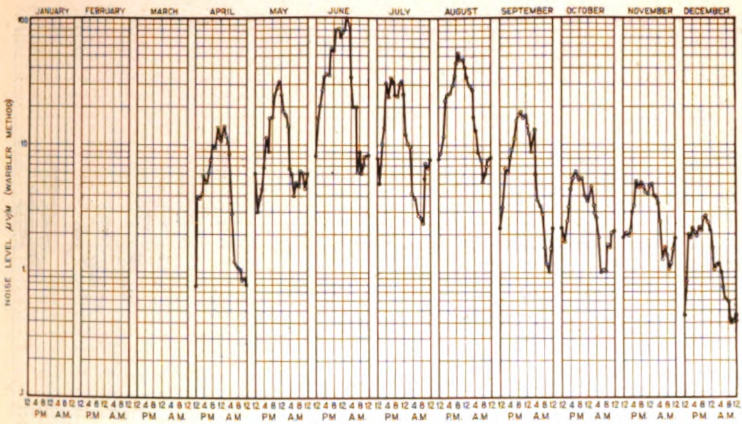
Monthly Averages of Diurnal Variation of Noise. New Southgate, England
57,000 Cycles
1923—1924



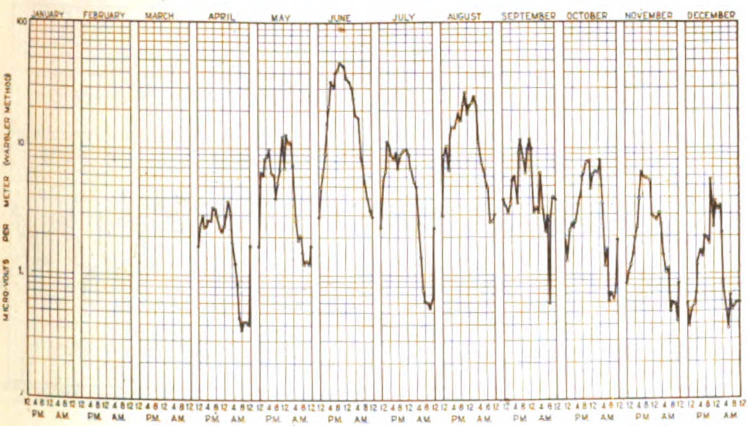
Monthly Averages of Diurnal Variation of Noise. Belfast, Maine
15,000 Cycles
1924



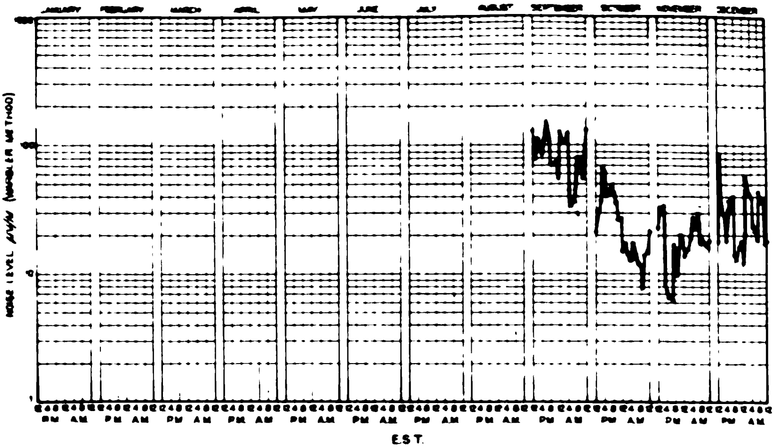
Monthly Averages of Diurnal Variation of Noise. Belfast, Maine
24,000 Cycles
1924



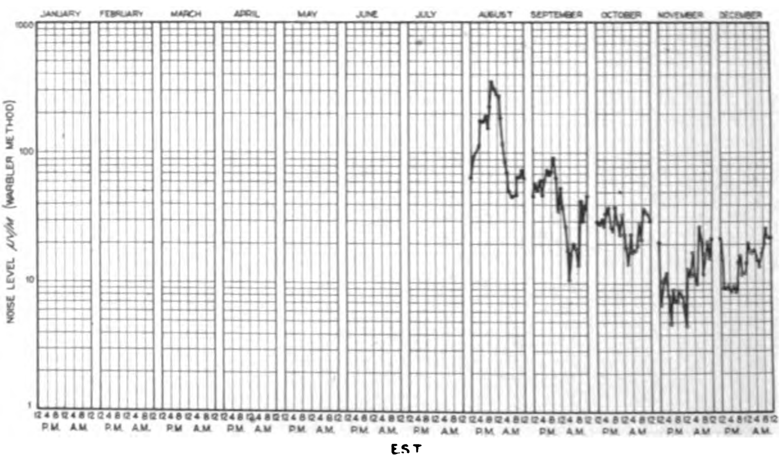
Monthly Averages of Diurnal Variation of Noise. Belfast, Maine
36,000 Cycles
1924



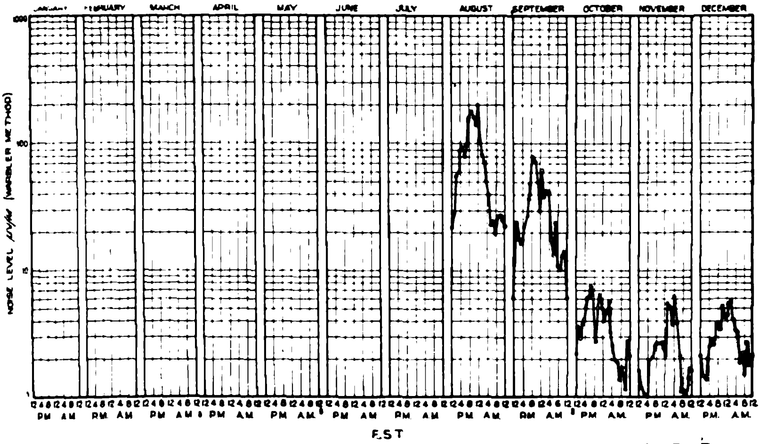
Monthly Averages of Diurnal Variation of Noise. Belfast, Maine
52,000 Cycles
1924



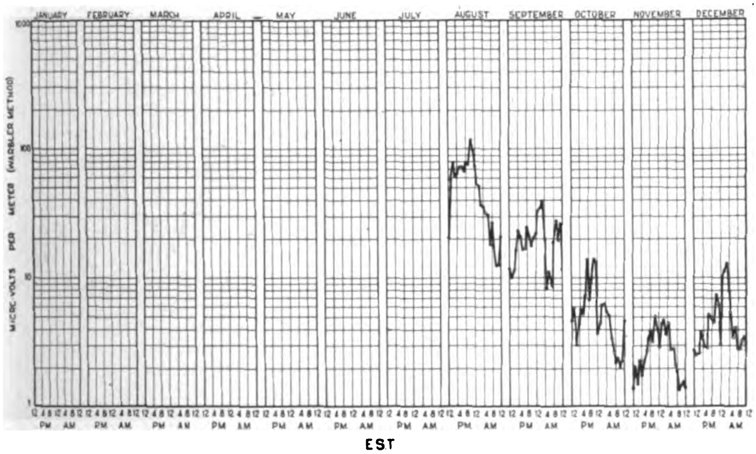
Monthly Averages of Diurnal Variation of Noise. Riverhead, L. I.
15,000 Cycles
1924



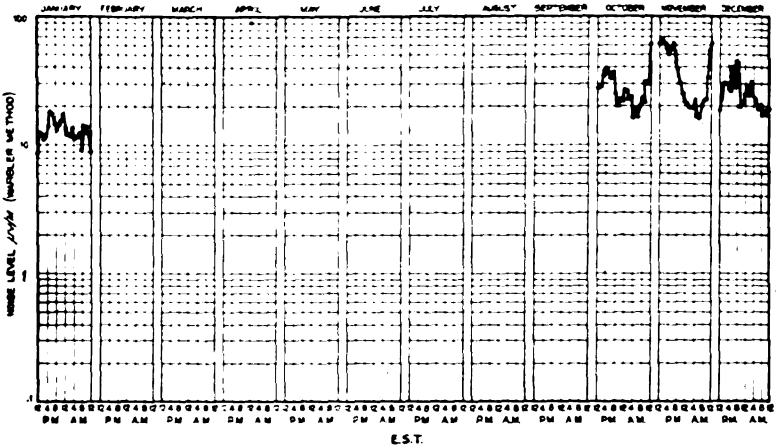
Monthly Averages of Diurnal Variation of Noise. Riverhead, L. I.
24,000 Cycles
1924



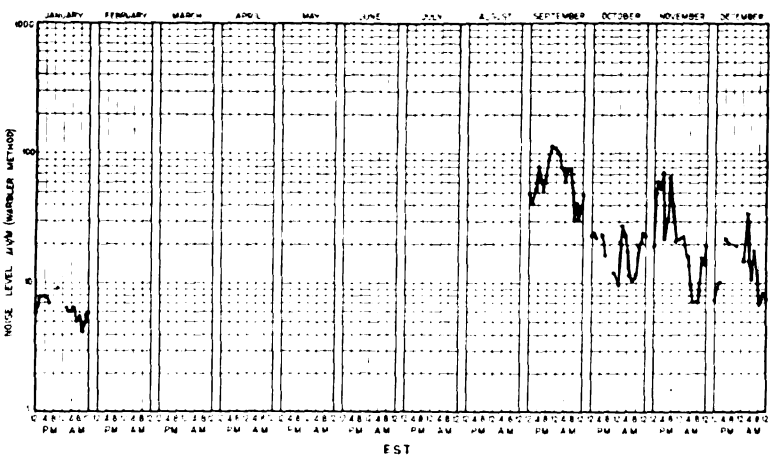
Monthly Averages of Diurnal Variation of Noise. Riverhead, L. I.
36,000 Cycles
1924



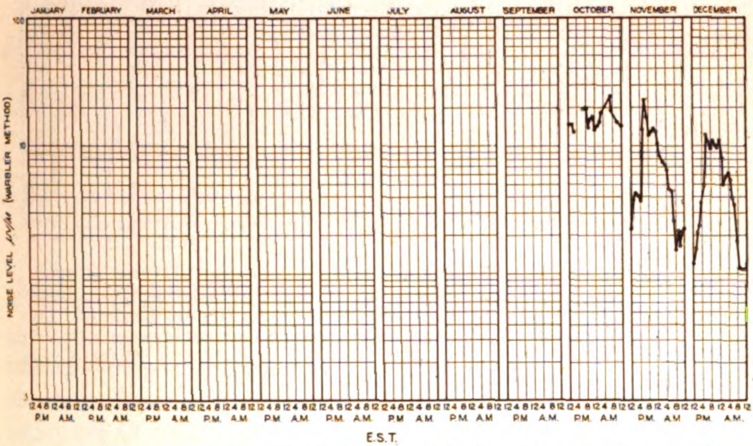
Monthly Averages of Diurnal Variation of Noise. Riverhead, L. I.
52,000 Cycles
1924



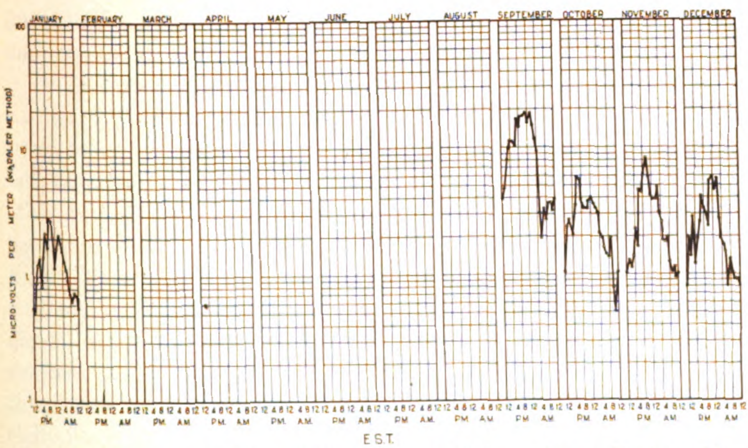
Monthly Averages of Diurnal Variation of Nouse. Green Harbor, Mass.
15,000 Cycles
October, 1923—January, 1924



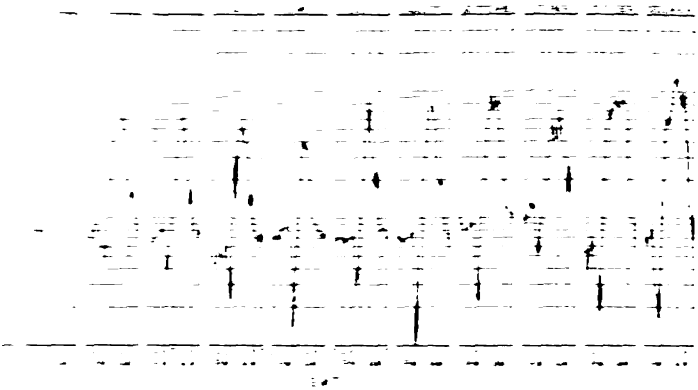
Monthly Averages of Diurnal Variation of Noise. Green Harbor, Mass.
24,000 Cycles
September, 1923—January, 1924



Monthly Averages of Diurnal Variation of Noise. Green Harbor, Mass.
34,000 Cycles
1923



Monthly Averages of Diurnal Variation of Noise. Green Harbor, Mass.
55,000 Cycles
September, 1923—January, 1924



[illegible] Averages of Diurnal Variation of Signal Field Strength. Rocky [illegible] L. I., U. S. A. (2XS) Measured at New Southgate, England. Corrected to 500 Amperes Antenna Current.

[illegible] Km. 57,000 Cycles

January, 1923—December, 1924

SOME STUDIES IN RADIO BROADCAST TRANSMISSION

By

Ralph Bown, DeLoss K. Martin and Ralph K. Potter

Department of Development and Research, American Telephone and Telegraph Company

One of the things which must be given increasing attention, if the technique of radio telephone broadcasting is to consolidate and continue its remarkable progress, is the mechanism of the transmission of radio signals through space. In many receiving situations the largest apparent defects present in the reproduced signal are those suffered not in the terminal apparatus but in transit through space, and in these cases better methods of utilizing the transmitting medium must precede any major betterment in overall results. In the present paper we are reporting some investigations in this field of radio transmission which have uncovered a number of interesting facts and have led to at least one conclusion which is of practical utility.

Nighttime transmission, which is the usual case in broadcasting, is in many places commonly marred by fading and sometimes by actual distortion of signals. Often these occur in certain areas not more distant from the transmitting station than other areas which enjoy freedom from such annoyance. Selecting a particular instance of these difficulties in an area near New York City which, in so far as can be judged at present, is probably a typical instance, we have subjected it to an intensive experimental study to determine what is the inherent nature of the troubles and if possible how thay may be alleviated. In doing this it has been necessary to employ novel forms of tests especially fitted to bring out in a concrete way the phenomena being investigated.

To provide a suitable background for the subject we have started our discussion below with a brief recital of some of the things which a transmission medium is called upon to do. Following this we have described our tests, pointing out in what ways the existing media seem to fall short of doing these things and offering certain speculations as to the reasons for the short-

comings. In conclusion, we have analyzed some practical problems in the light of this work.

Fundamental Considerations

As the radio art has progressed from spark telegraphy into continuous wave telegraphy and into high quality radio telephone broadcasting, increasing demands have been made on the transmission medium to deliver at the receiving point a true sample of what was put into it at the transmitting station. The requirements have grown in rigor because in telegraphy the end has been to develop increased reliability of communication at longer ranges and in telephony the medium is called upon to transmit a highly complex form of intelligence.

Of the requirements placed on the transmission medium by modern uses, those imposed by telephony are far more exacting than those for telegraphy. In telegraphy a single frequency, or at most a narrow band of frequencies sent out intermittently in accordance with a dot and dash code must reach the receiving station in such shape that it may be converted into audible sound for aural interpretation or into current pulses for the operation of relays or recording instruments. Leaving aside noise, the principal requirement is a sufficient freedom from fading so that signals can be interpreted or recorded without interruption. In radio telephony, as at present practiced in broadcasting, there is transmitted a modulated high-frequency wave comprising a relatively wide band of frequencies, usually at least 10 kilocycles. Such a modulated high-frequency wave drawn out in the familiar graphical representation is a comparatively simple-looking thing, but analyzed into its elements and studied in detail it is revealed as being an intricate fabric of elemental waves so interwoven with each other that no one of them can be disturbed without changing in some degree the complexion of the whole. For perfect results the whole band must arrive at the receiver with an amplitude continuously proportional to that leaving the transmitter, or the inflections or expression of the speech or music will not be correctly reproduced. All the component frequencies within the band must be unchanged in their relative amplitudes lest the character of the sounds be altered. Even the relative phase relations of the various frequencies must be preserved or, as will be shown later, the interaction of the two side bands in the receiving detector will result in the partial loss of some of the frequency components.

It is not long since the time when radio was supposed to be the

perfect medium for voice transmission, it being presumed that since the ether of space (if there be such a thing) was substantially perfect in its electrical characteristics it must transmit frequency bands carrying telephone channels without distortion of any kind. This may be true theoretically of a pure ether, but in fact, the ether used for radio communication is filled with a number of things ranging from gaseous ions down to the solid bed rock of the earth. It is rather to be expected that these will affect the progress of electromagnetic waves, and we know from experience that they do. Diurnal variations of attenuation, fading, directional changes, dead spots and the like are already well-known phenomena, resulting from the complexity of our transmission media, although no entirely adequate explanations of their causes have been certainly established. One of the most recent manifestations of the effects of irregularities in transmission through space is in the distortion of the quality of telephone signals. This was perhaps first noticed in the use of short waves for broadcasting, it being found that frequently the transmission was so distorted that after detection the signals such as speech and music were in severe cases almost unrecognizable.

Preliminary Investigations

For some time after quality distortion was recognized as a characteristic of existing short wave transmissions, it was thought that for the lower broadcasting frequencies, at least, it was present only at night and at relatively very great distances from the transmitter. However, careful observations demonstrated that there were points relatively near New York City where quality distortion from several broadcasting stations in the city was marked at night, and in at least one case was detectable even in daytime. When the station 2XB, the Bell Telephone Laboratories' experimental station at 463 West Street, New York City, was used to transmit test signals, it was found that quality distortion could be observed in northern Westchester county and in southern Connecticut at distances of about 30 to 50 miles from the transmitter. Fading was also pronounced, and it was noted as a significant fact that distortion was always accompanied by some fading although the reverse was not consistently true. In the course of these trials it was noticed that at a particular point near New Canaan, Connecticut, signals from 2XB were much weaker and more distorted than signals from 2XY, the experimental station of the American Telephone and Telegraph Company at 24 Walker Street, New York, even though the transmitter

at 2XB was about ten times more powerful. Daylight field strength measurements at this point showed that the field strength of 2XB was only one-third that of 2XY. This led to the rather startling conclusion that there is a ratio of 100 to 1 in the power efficiency of transmission to that particular receiving point from these two transmitting stations in New York which are only about one mile apart.

In order to throw some light on this state of affairs, a field strength survey was made by G. D. Gillett which resulted in the field strength contour map[1] here reproduced in Figure 1. The

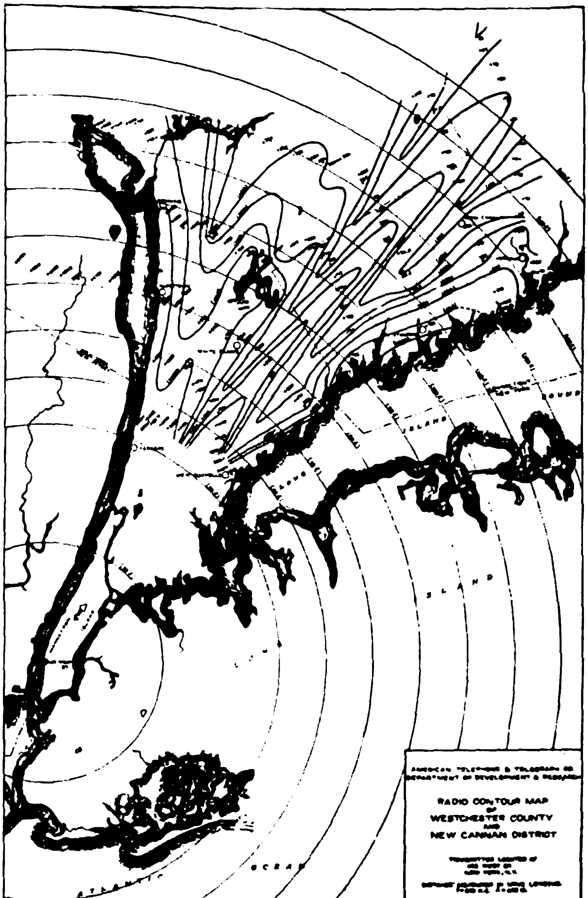


FIGURE 1—Radio Contour Map Showing Wave Interference Pattern

[1] This map was prepared by Mr. Gillett using the methods discussed in a aper "Distribution of Radio Waves from Broadcasting Stations Over City Districts," by Ralph Bown and G. D. Gillett, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 12, number 4, page 395, August, 1924.

contours on this map show that there is a series of long nearly parallel hills and valleys of field strength which, extrapolated,, would converge in lower Manhattan and which extend out to the northeast as far as it was thought worth while to follow them. There has occurred to us no better explanation of this hitherto unchartered form of field strength distribution than that it is a gigantic wave interference pattern. A detailed discussion of this theory is given in another section of this paper.

The fixed pattern shown by Figure 1 is definitely present only in the daytime, but that it is fixed is attested by the fact that a second survey made about a year later checks with the original one quite closely. At night fading is pronounced in the area covered by the pattern and it is apparent that some other factors must enter. As a result of an endeavor to check up the pattern at night it was discovered that quality distortion was, in general, most evident at places which were, by day, in the valleys of the field strength diagram, and a point in one of these valleys near Stamford, Connecticut, was selected for the establishment of a temporary field test station. The interior of this station, which was in the empty hay-mow of a barn, is illustrated by the photograph, Figure 2. At this place apparatus was set up to enable a study of the nature of the distortion in signals from 2XB. Many of the records discussed in succeeding paragraphs were taken at this Stamford field station. Others were taken near Riverhead, Long Island, which was also found to be well located for such work. Figure 3 is an outline map showing the relative positions of these field receiving stations and the transmitting station.

The reason for settling down at a fixed point in this way was to attack the problem from a new angle. The field strength, survey and aural observations had yielded much interesting information, but did not appear at that time to shed a gread deal of light on the quality distortion, so it was decided to attempt, by an oscillographic study of received signals sent out under rigorously controlled conditions, to determine just what alterations these signals suffered in their journey through space.

In finding such distortions the ear is, of course, the primary testing instrument or indicator of trouble, for, if the trained ear is unable to detect anything wrong with a received signal in comparison with its original counterpart it is safe to say that nothing detrimental of importance has happened to it. But the ear is a poor quantitative indicator and furnishes no permanent or easily analyzed record of its observations. It is evident that if we are to study quantitatively the characteristics of radio transmission

which give rise to quality distortion, we must devise tests which will disclose changes, of whatever kind, in the relations between the various component frequencies of the transmitted band and furnish interpretable permanent records. In fact, in the studies described herein, a considerable portion of the job was to devise or perfect suitable methods of attack.

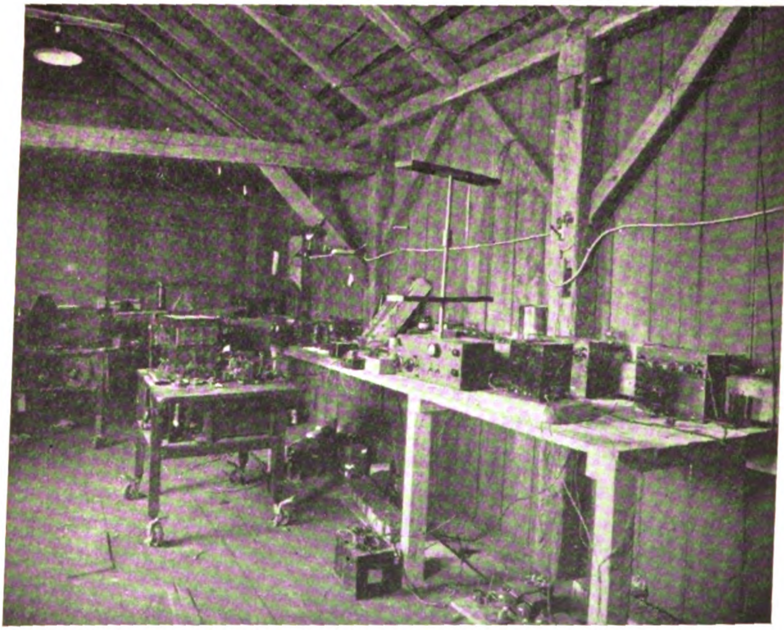


FIGURE 2—Interior View of Test Station Near Stamford, Conn.

FIGURE 3—Outline Map Showing Locations of Transmitting Station and Receiving Test Stations

SINGLE, DOUBLE, AND TRIPLE FREQUENCY TESTS

The variable factors in radio transmission which may be directly controlled are located at the transmitter and receiver. We have as yet no tangible means of controlling the transmitting medium, but it can be studied indirectly through the characteristics of the received signals. Obviously, it is desirable in the interest of simplicity to stabilize the apparatus variables to the extent that they may be idealized in considering observed results. Furthermore, at both the transmitter and receiver, it is desirable to make the antenna arrangements of the simplest form. For our work the normal antenna arrangement at station 2XB was used perforce, since any important changes would have constituted a major operation. It is far from a simple arrangement, as shown in Figure 4, which is an outline elevation and plan of the antenna and building at 463 West Street, New York City. Fortunately there are no buildings considerably higher than the antenna within a distance of several wave lengths.

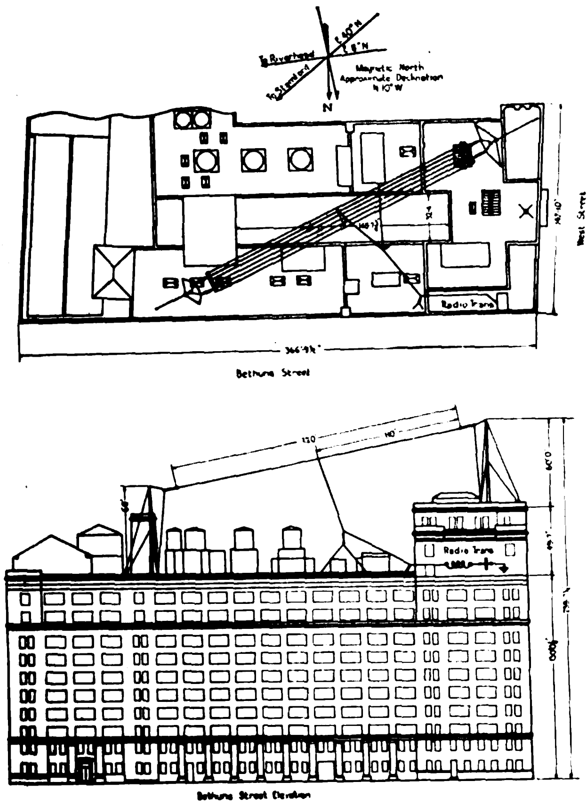


FIGURE 4—Plan—Elevation of the Transmitting Antenna

At the receiving test stations both loop and vertical antenna were used; but in most of the experiments a simple vertical antenna was employed. It was constructed of brass tubing, 30 feet long, and guyed in a vertical position. A galvanized iron pipe 12 feet long was driven in the earth for a ground connection. The vertical receiving antenna projected through the roof of the test station building at Riverhead, L. I., as shown in Figure 5. The receiving antenna was not tuned, but was connected to the radio receiver through fixed inductive coupling.

FIGURE 5—Receiving Test Station Near Riverhead, L. I., Showing Vertical Antenna Projecting Through Roof of Building

The carrier power in the transmitting antenna normally remains fairly constant, except for minor variations in voltage of the supply mains, and with a little care on the part of operating personnel, the antenna current can be kept within the limits of a 1 per cent. variation, which is small compared with the signal fading usually experienced.

The stabilization of the frequency was of the greatest importance since in some of the tests it was desired to beat or heterodyne the signals down to audio frequencies and pass them

through narrow band filters. To provide this stability engineers of the Bell Telephone Laboratories arranged the 5-kw. transmitter at station 2XB to obtain its carrier frequency by amplification of the output of a 610-kc. piezo-electric crystal oscillator.

When desired, some of the antenna current from the output of the transmitter was rectified and the resulting current was sent over a telephone line to the receiving station so that the frequency and wave form of the modulating signal could be seen and photographed at that point, thus guarding against any possible distortion in the transmitter and enabling a direct "before and after" comparison to be made. The telephone circuit was also used for communication between engineers at the two terminal stations.

At the receiving station double detection receivers and audio frequency amplifiers were employed. These did not have entirely "flat" transmission characteristics over the audio frequency band, but in most of the tests this was of no importance. In cases where it affected the results, the making of necessary corrections was a simple matter. In tests involving beating the received signals down to audio frequencies through the agency of a local heterodyning frequency, this was supplied from a shielded vacuum tube oscillator which on comparison with a standardized piezo-electric oscillator was found to possess the required stability. The double detection type receivers were used for no other reasons than their availability and their convenience for quantitative work. The beating down oscillator within the sets and the intermediate frequency step passed through in the sets by received signals do not figure in the following discussion of test methods, but, of course, in each case the necessary set tuning adjustments were made. To avoid confusion it is well to think of these receivers as being replaced by high-frequency amplifiers and simple detectors since the local beating oscillator referred to in later pages is the separate shielded oscillator described above which is used to beat the signals down to audio frequencies.

In this work the moving coil type oscillograph was used throughout for the purpose of making photographic signal records. As indicated in Figure 6, two oscillographs with elements connected in series were employed; one for the purpose of making a continuous record of the variation in the amplitude of the signal using a slow moving photographic paper tape and the other to obtain the wave shape of the signal by means of the usual high speed photographic film drum. An element of one oscillograph

was also used at times to record on the film drum the wave shape of signals rectified at the transmitting antenna and sent over the telephone lines.

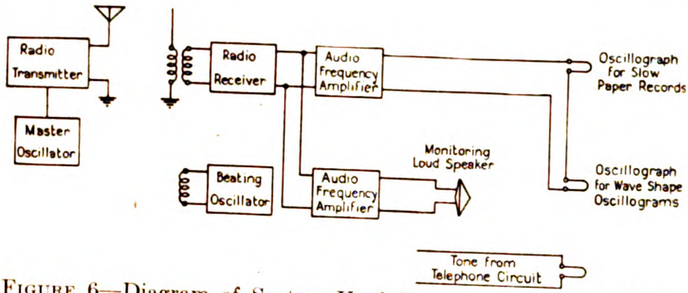


FIGURE 6—Diagram of System Used for Single Frequency Tests

Figure 7 is the interior view of the test station at Riverhead showing the general arrangement of the oscillographs and accessory apparatus. This oscillograph equipment formed about the

FIGURE 7—Interior View of Riverhead Testing Station Showing Recording Apparatus

only fixed portion of the apparatus, other portions being changed from time to time for different tests. These arrangements will be described later in connection with the records which they were used to obtain.

In considering these various records perhaps we had best look first at the simpler ones and then proceed in a more or less orderly fashion to the more involved ones. The simplest records are fading records of the unmodulated carrier frequency of 610 kc. At the receiver the carrier was heterodyned with a local oscillator to produce a beat tone of about 250 cycles, which was fed through amplifiers to the oscillograph elements.

A representative sample of the form of signal records made in the manner described above which show the variation in the amplitude of the received carrier signal with time, is given in Figure 8. It shows a typical fading record made at Stamford, Connecticut, May 16, 1925. The timing interval on strip 6 is 2.6 seconds.

The feed of the photographic paper tape through the oscillograph was varied somewhat during the course of the experiments, but was generally in the range of 6 to 12 inches a minute. At this rate the record of an audible frequency signal is a shadow band of varying width corresponding to twice the amplitude of the signal, as both the positive and negative half-cycles are recorded. It will be observed that the outer limits of the band corresponding to the peaks of the sine wave are darker than the center portion of the record. This is due to the fact that the rate of change of the movement of the light spot on the record is a minimum at the peak of the signal; hence, a greater quantity of light affects these portions of the record. This shading effect was very useful in the way it brought out changes in the distortion of the received signal. This is discussed fully in another section of the paper. The fuzzy irregular outline on portions of the records is caused by static and radio noise. The timing marks on the record allow a measurement of the time interval between points of minimum signal. Figure 9 is a sample oscillogram of the wave shape of a beat note signal recorded by the method described above.

Marked changes in the fading cycle or time interval between points of minimum signal may occur within a period of a few minutes, and from day to day there is often evidenced a modification of the general character and the recurrence of these changes. An example of this change in a short period of time is well illustrated by the oscillograms in Figure 10. Strips 1, 2 and 3 form a continuous record starting at 1.52 A. M.; strips 4, 5 and 6 start at 2.16 A. M.; and strips 7, 8 and 9 start at 2.37 A. M. These

are three sections of a continuous record selected for the purpose of showing the decrease in the fading period, in a 45-minute interval. The timing interval on strip 10 which applies to these records is 5 seconds. In this particular record only half of the

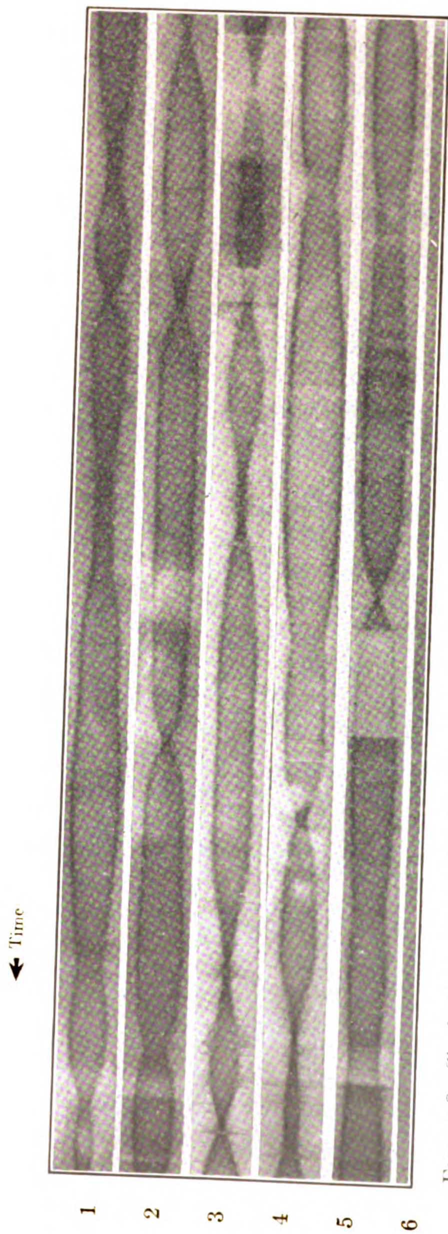


FIGURE 8—Single-Frequency Fading Record. Made at Stamford, Conn., May 16, 1924, 1.54 A. M. Timing Marks, on Strip 6, 2.5 Seconds Apart

audio signal was recorded, the edge of the strip being the zero line.

These single frequency fading records do not offer very much to work on. There is, however, just enough suggestion of regularity about them to annoy one with the thought that perhaps thay may follow some definite combination of periodicities, and with this in mind we have taken sections of two different records and subjected them to a harmonic analysis.

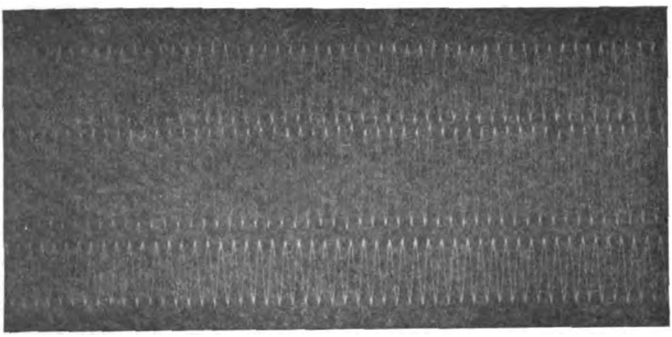


FIGURE 9—Wave Form of Beat Note Signal for Single-Frequency Test. Center Trace Signal from Vertical Antenna, Upper and Lower Traces Signals from Loop Antenna Receivers

So far we have been able to draw no more useful conclusions from such harmonic analyses than that the heterogeneous scattering of harmonic values is about what one would expect from the looks of the curves.

One significant thing about these oscillographic single frequency fading records is that they show no high speed fading of important magnitudes. Occasionally one cycle of the beat tone will be somewhat upset by a sudden change in the amplitude, but in general no changes which consistently distort the wave form were observed.

The slow fading may be considered as a modulation, and on this basis the received signal is seen to be composed of the original constant carrier frequency accompanied by very narrow side bands occupying at best perhaps a fraction of a cycle.

The next progressive step in the radio transmission studies is naturally from a single frequency to two or more frequencies transmitted simultaneously. By the use of two crystal oscillators at the transmitter, two separate and distinct radio frequency signals were transmitted simultaneously. These crystals were ground by the Bell Telephone Laboratories to oscillate at 610,000

cycles and 609,750 cycles. The amplitudes of these signals at the transmitter were controllable so that it was possible to make them equal, or one larger than the other, equivalent to the relative magnitudes usually found for the carrier and single side-band

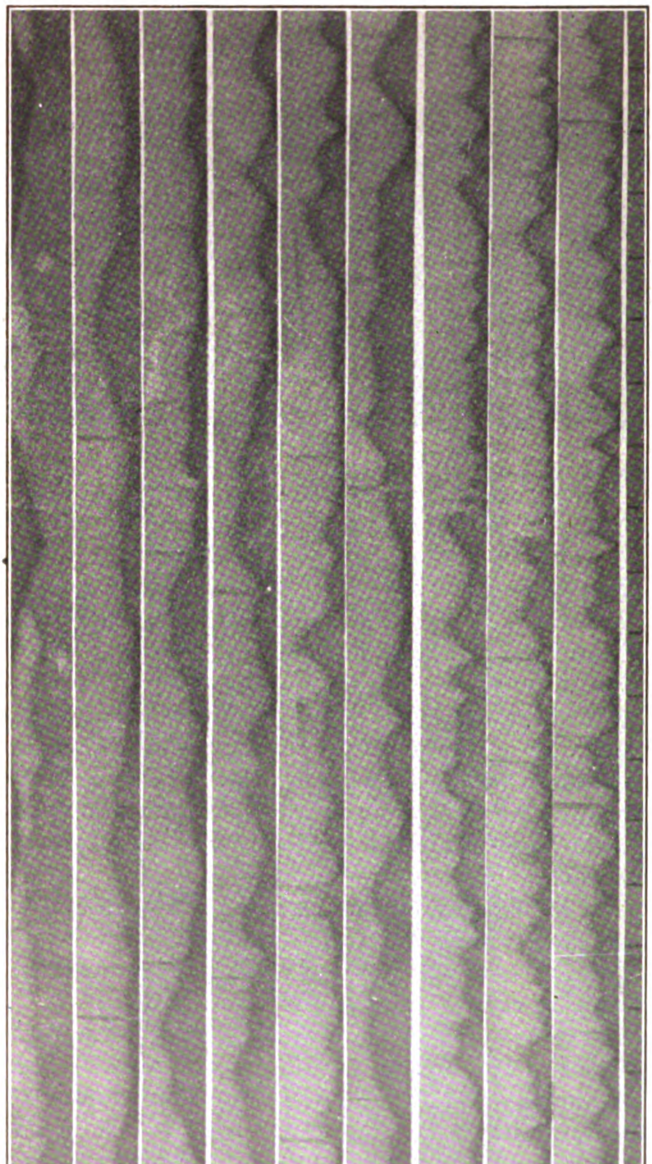


FIGURE 10—Single Frequency Fading Record, Showing Variation in Rapidity of Fading, Made at Riverhead, L. I., July, 16, 1925, 1.52 A. M. Timing Marks, on Strip 10, 5 Seconds Apart

transmission case. Records were obtained of the variation of these radio signals, but none is reproduced here since the information shown by them can be just as easily obtained from the triple frequency records shown below.

Radio transmission on three frequencies is readily obtained by modulating the carrier with an audio frequency tone, and observing the three frequencies separately at the receiver.

If the modulating tone is

$$\sin (vt+\phi)$$

and the carrier signal

$$A \sin pt,$$

the transmitted signals are

$$+\frac{Aa}{2} \cos [(p+v)t+\phi] \qquad \text{(upper side band)}$$

$$+A \sin pt \qquad \text{(carrier)}$$

and

$$-\frac{Aa}{2} \cos [(p-v)t-\phi] \qquad \text{(lower side band)}$$

where a is a constant proportional to the percentage modulation.

These three frequencies are not merely a mathematical fiction, but are physically existent as three separate waves bound together only at their point of origin.

To adequately record them separately by means of the oscillograph, advantage was taken of the fact that a group of frequencies beaten with a single frequency differing from them by a small amount and detected may thereby be reduced to audible frequencies without having their interrelations of phase, amplitude or difference frequency composition, changed in any respect. For instance, if the frequencies expressed above are beaten with a local constant frequency,

$$B \cos (qt+\psi)$$

the resultant lower or difference frequencies will be

$$+\frac{kBAa}{2} \cos [(p+v-q)t+\phi-\psi]$$

$$+kBA \sin [(p-q)t-\psi]$$

$$-\frac{kBAa}{2} \cos [(p-v-q)t-\phi-\psi]$$

Each one of the three components has been changed in amplitude by the same factor kB representing the efficiency of detection. Each one has been reduced in frequency by exactly the same amount $\frac{q}{2\pi}$ and each has had its instantaneous phase shifted by

an angle $-\psi$. Relative to each other they remain unchanged.

In our actual case the carrier frequency $\frac{p}{2\pi}$ was 610 kc. The modulating frequency $\frac{v}{2\pi}$ was 250 cycles and the beating frequency $\frac{q}{2\pi}$ was 608,375 kc., so that the resulting three audio frequencies were 1,875 cycles, 1,625 cycles and 1,375 cycles.

As indicated in Figure 11, in order to make a record of these signals they are separated at the receiver by means of band filters. These filters and others similar in type for other modulating frequencies were designed and made by the Bell Telephone Laboratories especially for this work. The band filters used for the purpose of selecting the carrier and side-band frequencies had a cutoff of 40 Transmission Units 250 cycles from the mid-band frequency.

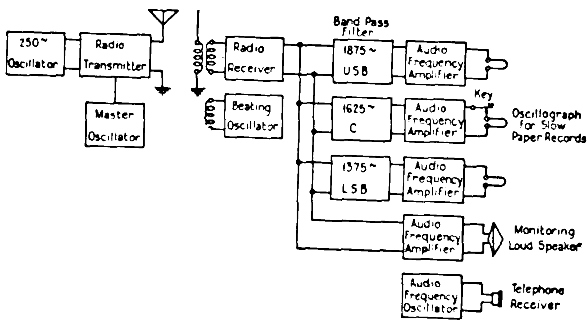


FIGURE 11—Diagram of System Used for Three-Frequency Tests

These cutoffs, together with the position in the frequency range of the pass bands of the filters, preclude any troubles from cross modulation of the radio carrier and side bands during the beating down process. The products of such cross modulation would be frequencies which are multiples of 250 cycles, and these cannot pass the filters. On the other hand, the beaten down frequencies will pass practically intact, since, as has been shown by the previously described single frequency tests, each of the three frequencies received, although subjected to amplitude modulation, by fading, represents only a very narrow band of frequencies for which the filter pass bands were of adequate width.

As the modulating tone was carefully calibrated to 250 cycles and the filters adjusted to transmit the frequencies specified, it was only necessary to transmit the carrier while adjusting the

receiving beating oscillator. The following procedure for this adjustment was found to be very successful. A local audio frequency oscillator was set to the reduced carrier frequency of 1,625 cycles, and its output connected to a telephone receiver. The audio beat note from the radio signal and local beating oscillator was reproduced by a loud speaker and its frequency adjusted to zero beat the 1,625-cycle tone from the telephone receiver.

When this adjustment had been completed the carrier was modulated with the 250-cycle tone, and the side-band signals automatically passed through their respective filters.

The signals from the outputs of the filters were amplified, and recorded separately by the three oscillograph elements. The sample records shown in Figure 12 are representative.

Strips 1, 2 and 3 are taken from a long record obtained May 7, 1925, 3.22 A. M. The upper trace is a record of the upper side-band signal, the center trace the carrier, and the lower trace the lower side band. Strips 4, 5 and 6 are from a section of a similar type of record made May 23, 1925, 1.06 A. M., where the carrier was modulated with a 500-cycle tone and different filters were used. In this record the upper trace is the lower side band and the lower trace the upper side band.

It will be noticed that the timing interruption appears only in the side-band signals, as the tone was interrupted before modulation took place, and that the amplitude of the carrier signal is not affected by the interruption of the modulating tone. This makes it very easy to identify the side-band signals. These records give an excellent graphic picture of ordinary radio telephone transmission, bringing out the fact that three truly individual frequencies are transmitted to reproduce one.

In Figure 12, strips 1, 2 and 3, the relative amplitude of the three signals are very nearly in proportion to the relative amplitudes of the signals as they existed in the ether at the receiving point. Before this record was made a transmission characteristic of the complete receiving circuit, including the oscillograph elements, was obtained, using a local transmitter with modulated carrier for the purpose of making the measurement. The gain of the audio amplifiers at the outputs of the filters was adjusted to give substantially uniform transmission on each of the three frequencies corresponding to the carrier and side bands of the radio frequency signal.

As shown in Figure 11, a telegraph key is placed in the circuit of the center oscillograph element, for the purpose of placing identifying signals on the records. An example of these identifying signals is shown in Figure 12, strip 4, which gives the date and

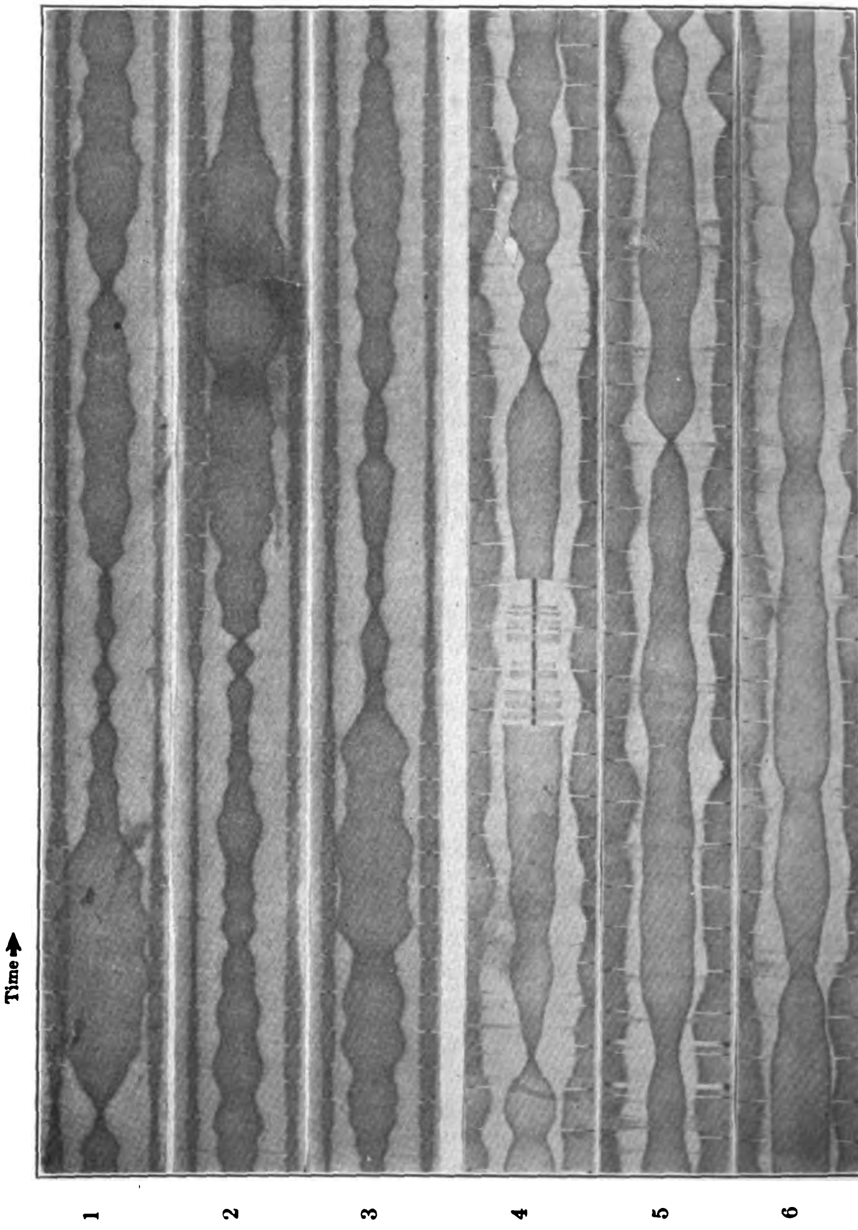


FIGURE 12—Fading Record Showing Individually the Fading of Carrier and Side-Band Frequencies. Made at Riverhead, L. I. Timing Interruptions in Side-Band Signals, 5 Seconds Apart

time the record was started, July 23, 1925, 2.06 A. M. (Eastern daylight saving time).

The record in Figure 13 is of the carrier and side-band signals with 500-cycle modulation made at Riverhead, L. I., May 25,

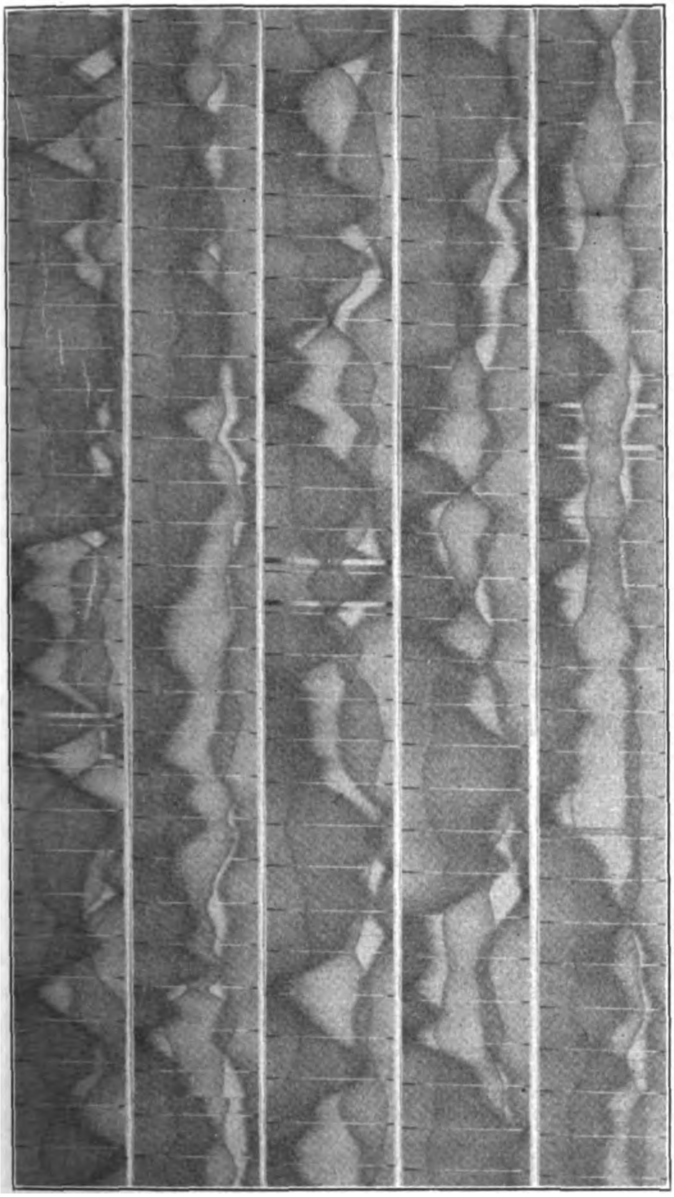


FIGURE 13—Fading Record of Carrier and Side-Band Signals, Made at Riverhead, L. I. Timing Interruptions in Side-Band Signals, 5 Seconds Apart

1925, 1.25 A. M. More gain was used in the side-band amplifiers for this record in order that the effects of fading could be brought out more prominently. In this record only half of the side-band signals were recorded, the zero reference line being at the edge of the strip. The upper trace is the upper side band, the center the carrier, and lower trace the lower side band. Where the traces of the signals overlap, a darker record is obtained. This record may be confusing at first, but if strip 5 is examined where the amplitudes of the signals are not so large, a better picture of the form of the record will be obtained.

It is obvious from these records that the carrier and side-band signals do not fade together as a unit. The carrier may pass through a zero value with still considerable amplitude in the side-band signals, as in strips 1 and 3. In the first case, strip 1, the three frequencies successively fade through points of minimum signal in the order lower side-band, carrier and upper side-band; and in the second case, strip 3, the three frequencies fade through points of minimum signal in the reverse order. This is a definite indication of *selective fading*; that is, *fading is a function of frequency as well as time.*

An endeavor to form an explanation of the cause of this selective action in fading must be largely in the nature of speculation. Furthermore, since our data consist in the results of things which have happened rather than in any first-hand information on the processes of the happening, the building of an explanation is a synthetic process. In general, for any given set of facts it is possible to synthesize a number of explanations. Bearing this philosophy in mind we have considered various theories in connection with our observations and have concluded that simple wave interference as a major cause of the signal variations is at present the most likely explanation. While wave interference may be called a major cause it should perhaps also be called a secondary cause, since the assumption of wave interference presupposes for its origin, primary causation by some physical state or configuration of the transmission medium. Speculation as to the nature of this primary cause is one stage further removed from the data contained in our oscillographic records than is the assumption of wave interference.

Since it is desirable in the remainder of this discussion to point out the evidences of wave interference, let us consider briefly the nature of this phenomenon.

To avoid any possible confusion of terms, let it be said that by "wave interference" we mean a particular physical phenome-

non in wave transmission and have no reference whatever to static, signals from other stations, or any other of the forms of radio noise which are commonly designated by the word "interference" when they hinder the reception of desired signals.

When two single frequency plane polarized wave trains start out at the same time from a common source and travel by different routes to meet again at a distant point, the nature of disturbance at that point is determined by the relative space phases of the planes of polarization and time phases of the amplitude of the two arriving waves.

If we let E represent the vertical resultant of the electric field, which would be the only part affecting a simple vertical antenna, such as we have used in most of our tests, then

$$E = e_1 \sin 2\pi \, (F\,t + d_1) + e_2 \sin 2\pi \, (F\,t + d_2) \qquad (1)$$

where F is the frequency and d_1 and d_2 are the distances along the respective paths measured in wave lengths and e_1 and e_2 are the vertical components of the two waves. These two sine terms may be thought of as two vectors differing in phase.

The condition that these add giving a field

$$E = (e_1 + e_2) \sin 2\pi F t$$

$$\text{is that, } d_1 - d_2 = \text{(a whole number)} \qquad (2)$$

that is, the difference in length of the two paths must be an exact whole number of wave lengths. The condition that the two waves cancel each other giving a field

$$E = (e_1 - e_2) \sin 2\pi F t$$

$$\text{is that, } d_1 - d_2 = \text{(a whole number)} + \tfrac{1}{2} \qquad (3)$$

that is, the difference in length of path must be an exact odd number of half wave lengths.

Thus if the two components e_1 and e_2 are equal, the resultant vertical field E will go through values ranging from $(e_1 + e_2)$ down to zero as the path lengths change relative to each other. If the two waves do not have exactly the same amplitude, the minimum value of E will be something more than zero.

Differences in attenuation of the two waves and differences in their direction of arrival will modify the relative amplitudes of e_1 and e_2, but will not modify the time relations required for minima of the resultant field E unless we assume that at the time of a minimum neither wave has an appreciable vertical component. Since the consequences of such an assumption do not accord with

our experimental data, we have considered that it may be left out of account in the present discussion.

This is obviously a picture which fits in very well with the simple single frequency fading records. The major maxima and minima occur when the conditions of equations (2) and (3) are met and e_1 and e_2 are nearly equal. On the other hand, it seems doubtful that the picture can be so simple. If we suppose two wave paths, why not three or more? Additional paths would add irregularities to the fading and it would not be necessary to assume as great a degree of irregularity in the changes in any one path. But with an increasing number of paths the various arriving waves would tend to average to a more or less constant mean value, and large departures from this mean would become rare. The fact that the fading signal continually covers a large range of amplitude, with the maximum many times the minimum, definitely points toward there being but a very small number of major paths, probably not more than two.

Considering now the question of selective fading in relation to wave interference, we refer back to equation (2).

If we assume the distances to be measured in any desired units and call them d_1' and d_2' our equation will still hold provided we divide each distance by the wave length measured in the same units, thus

$$\frac{d_1'-d_2'}{\lambda}=\text{a whole number}=x;$$

rearranging this and writing $\frac{V}{F}$ for λ where V equals the velocity of the waves, we have

$$F=x\left(\frac{V}{d_1'-d_2'}\right). \tag{4}$$

If now we assume $(d_1'-d_2')$ to be fixed, we find that F can have a series of values which are integral multiples of $\frac{V}{d_1'-d_2'}$, which we may call the frequency spacing interval. That is, with changing frequency E will go through maximum values with frequency at a series of frequencies beginning theoretically with zero and extending upward in regular spacing to infinity.

The spacing interval is obviously that number of cycles which corresponds to the lowest finite frequency in the series, namely, the frequency for which the distance $(d_1'-d_2')$ is just one wave length since when $x=$ unity, equation (4) becomes

$$F_1=\frac{V}{d_1'-d_2'}=\text{the spacing interval}. \tag{5}$$

By using the same process on equation (3) we find that E has minimum or zero values at another series of frequencies having the same spacing interval but lying midway between the frequencies at which maxima occur.

Thus it is apparent that with fixed path length difference the amplitude of the field E will be different for different frequencies, ranging from maxima of (e_1+e_2) down to minima of zero if the polarization planes and amplitudes of the two vertical components are equal.

Furthermore, still thinking of equation (1) as representing two vectors, it is evident that the phase of the resultant field is different for different frequencies even though these different frequencies had exactly the same starting phase at the source.

If the paths are changing with time, the field at a given point, as has already been pointed out, will go through time fluctuations. Another way to look at this is that there is a space pattern of maxima and minima, and as the paths change, the plane section of the pattern taken by the surface of the earth wanders so that at any one point the field is continually fading in and out as the maxima and minima glide by it. Each frequency has its own pattern differing from those of its neighboring frequencies in such a way that at any given point the relation between amplitude and frequency is that just discussed above. Thus as the paths change and the patterns shift, the different frequencies fade not simultaneously but progressively.

In the above analysis of wave interference it has been assumed that all frequencies traveled from transmitter to receiver over a given path in the same elapsed time. This does not mean that they necessarily follow exactly the same route on this path, since they might follow somewhat different routes of equal length or if their transmission velocities were different, they might follow different routes of unequal length and still come within the definition of a "path." It seems reasonable to assume that over the width of an ordinary transmitted band the various frequencies are treated alike by the medium, and the simple assumption that they follow the same route with the same velocity is justified. If none of these assumptions is correct, but the departure is not large, the effect will be merely to introduce slight irregularities into the spacing interval and the general nature of the result will not be changed.

Let us now examine more closely the record, a part of which is shown in Figure 13. A portion of this has been condensed into

the curves of Figure 14. One unit along the time axes of these curves represents a 25-second interval.

To obtain these curves the amplitude of the signal has been scaled off and plotted, ignoring all the minor irregularities. From this record the relative fading characteristics of these single frequency signals 500 cycles apart are more easily seen, and it is possible to contrast the time of occurrence of points of minimum signal for any pair of them.

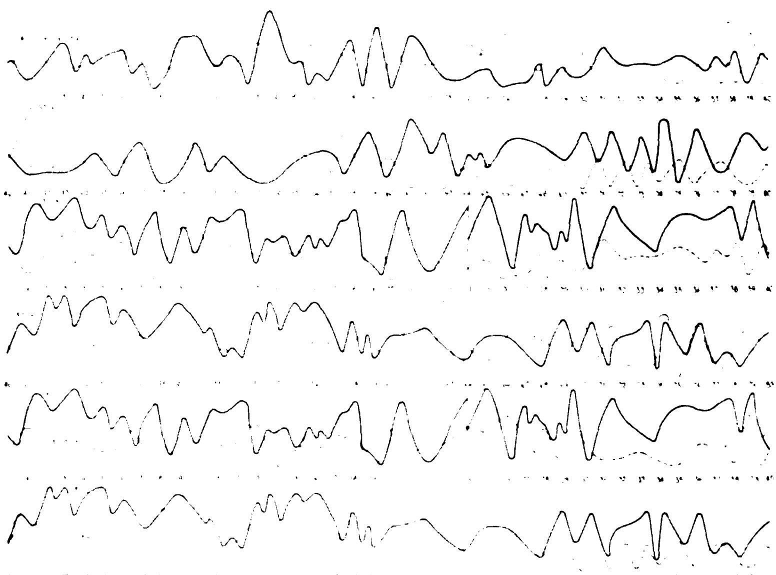


FIGURE 14—Plotted Curves of Signal Amplitudes Condensing a Long Fading Record, Part of Which is Shown in Figure 13. Numbers Along Time Axis Correspond to Successive 25 Second Timing Interruptions

For the frequency difference of 500 cycles (610.5−610 and 610−609.5) these times are obviously quite different, but there is no clearly discernible relation between them. The curves for 1000-cycle difference (609.5−610.5), however, show a striking relation in that the maxima and minima of the two are opposed fairly regularly over the entire 33-minute interval covered by the plot. This means that when one frequency has a minimum amplitude the other has a maximum, and vice versa. Certainly this suggests a wave interference involving only two major paths whose difference in length is such that the spacing interval is 2,000 cycles. The path difference appears to be changing somewhat irregularly but at an average rate of the order of one wave length (or approximately 500 meters) per minute.

Before speculating further on the numerical values which may be derived from this part of the data, we had perhaps best consider some other records of a somewhat different kind which are better adapted to provide such values. But first let us reiterate that these are *night-time* effects.

During the day signals substantially uniform in amplitude are received. An example of the type of transmission obtained in the daytime is given in Figure 15, which is a record of the carrier and side-band signals received with substantially the same terminal conditions with the exception of the time as that existed when the records shown in Figure 12 were made.

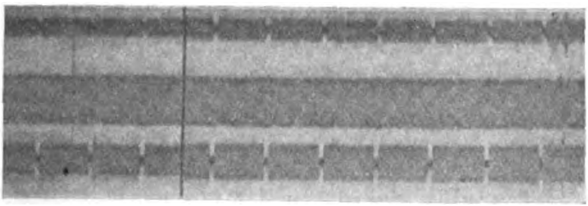


FIGURE 15—Daytime Record of Carrier and Side-Band Signals

The abrupt change in the amplitude of the side-band signals was due to an intentional change at the transmitter in the input level of the tone modulating the carrier, and accordingly the amplitude of the carrier did not change. The timing interval is 5 seconds.

BAND FADING RECORDS

The familiar fading record is limited to two axes, amplitude and time. So far we have extended this cramped perspective somewhat by observing as many as three separate fading records spaced at audio frequency intervals along the frequency axis. Even these three narrow lookouts upon the wide range of ether transmission have indicated amplitude relations along the frequency axis which promise to open a new line of attack upon the problem of night-time fading. But the desirability of knowing what takes place in the interval unrevealed by these cracks in the fence becomes obvious. We should like to know the relative amplitude of frequencies over a wide band, and the change in this relation with time.

Since it is not a simple matter to record simultaneously the amplitude of a large number of waves of frequencies separated by say one hundred cycles in the radio frequency range, a single

frequency in combination with a frequency stepping device at the transmitter has been adopted. The circuit arrangement is shown diagrammatically in Figure 16. The rotary contactor

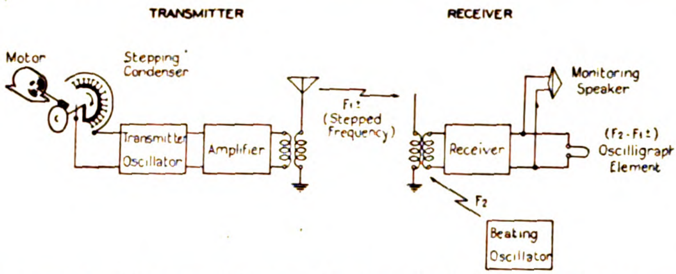


FIGURE 16—Diagram of System Used to Obtain Records of Selective Fading or "Band Fading" Records

bringing into the circuit successively a total of fifteen small condensers across the main condenser of the transmitter oscillator shifts the frequency in steps over an adjustable range. The contactor is rotated at the rate of nine revolutions a minute, which is sufficiently slow to show definite steps in the oscillograph record. At the receiving end a local oscillator supplies a radio frequency wave for beating the incoming frequencies down to values within the audible range.

A long oscillograph record of this stepped frequency gives a sort of moving picture of the fading for the entire band covered.

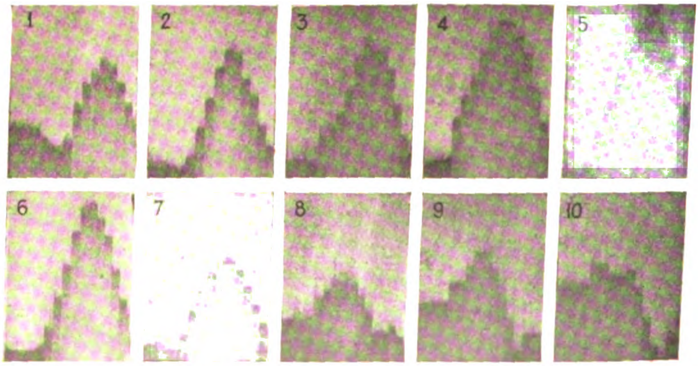


FIGURE 17—Sample Band Fading Record

A sample of such a record is shown in Figure 17 with alternate pictures in the series removed to simplify the relations, since by reason of the two-way traversal of the frequency band successive

pictures are reversed. If a series of such built-up pictures as these could be taken rapidly on moving picture film, and projected successively upon a screen we should have before us an animated view of band fading. And according to the results of experimental investigation the subject offers a lively theme for such a presentation. The peaks and depressions glide nervously back and forth across the setting. The successive pictures of Figure 17 (which, by the way, were selected for their half-tone reproduction possibilities rather than as first-class examples of the records taken) illustrate a rather leisurely movement of this sort. These ten built-up photographs cover a period of slightly more than one minute. In the first seven pictures a depression appears at the left, while in the last three this depression seems to have made an exit followed by the simultaneous entrance of another from the opposite wing of the stage. Evidence of such organized spacing of the minima is present in all these night-time band fading records. As has already been suggested, such evidence has an important significance, but before going into this phase of the subject again let us examine a little more in detail the structure of these band fading records.

The steps in any one picture of Figure 17 are, as we have said, snapshots of the wave amplitude for successively different radio frequencies taken about a quarter of a second apart. The fact that the fifteen snapshots used to build up a single picture are not taken simultaneously causes a skewing of the outlines when movement of the depressions as shown in Figure 17 occurs. If, for example, we were to take fifteen separate and successive snapshots of a mountain through fifteen long vertical slits side by side, it would be possible to combine the narrow sections so as to form a true picture of the peak. Now, if by some prodigious act of nature, the mountain were shifted suddenly to one side and back again during the time we were taking the fifteen successive snapshots through the vertical slits, the combination of them would form a profile quite different from that obtained when it was stationary. Or if it were simply moved steadily across the field of vision during the time the snapshots were being taken, one slope would be made to appear precipitous while the other would be leveled to a gentle grade in the finally built-up picture. The character of this skewing, then, and its magnitude depend upon the rate at which the object being photographed in vertical sections moves, and the direction of the movement.

In Figure 18 is shown an imaginary night-time band-fading record in the "assembled" form. Since such a record contains

frequency as a third dimension. in addition to amplitude and time as shown in the ordinary fading record, our simple fading curve has assumed the broader aspect of a surface, the selective fading making more or less parallel "valleys" running across it. The stepped-frequency system of recording the points amounts to photographing sections of this solid. The important point to be kept in mind is that these sections are *not perpendicular to the time axis.* If they were, the skewing previously described would not be present. By setting these sections up in their true relation to the time axis, however, and filling in to produce a continuous surface such as is shown in Figure 18, the

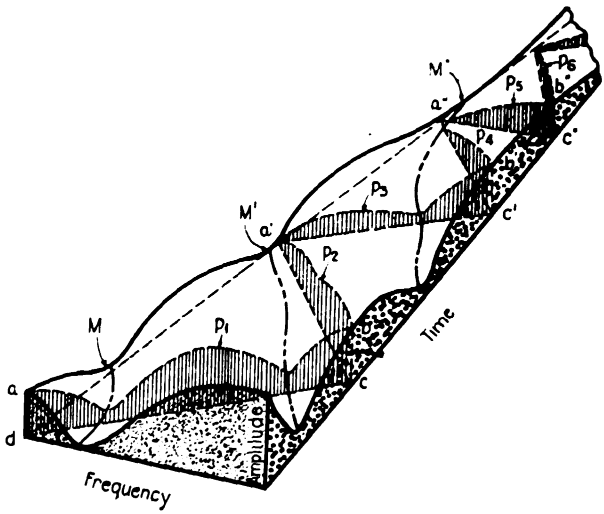


FIGURE 18—Three Dimensional Diagram, Showing the Method of Interpreting Band Fading Records

result is correctly represented. In order to make a detailed and accurate study of the band fading records, therefore, it is desirable to construct from the oscillograph sections the complete surface by the method suggested.

In Figure 18 the trace of minima crossing the band is shown by M, M' and M''. Picture sections obtained as our recording apparatus literally moves back and forth across this frequency band are shown as $(a-b-c-d)$, $(b-c-a')$, $(a'-b'-c')$, etc. It will be evident that the section P_1, for example, will, in case a minimum is crossing rapidly, appear entirely unrelated to section P_2. When the minima run nearly parallel to the time axis (slow changes in transmission conditions), the successive pictures P_1, P_2, P_3, etc., will reveal their relation by direct comparison.

Actually to obtain frequency-amplitude sections perpendicular to the time axis in Figure 18 would require the simultaneous transmission and reception of a large number of frequencies spaced at short intervals along the frequency axis. A more practical thought is to speed up the process and though this

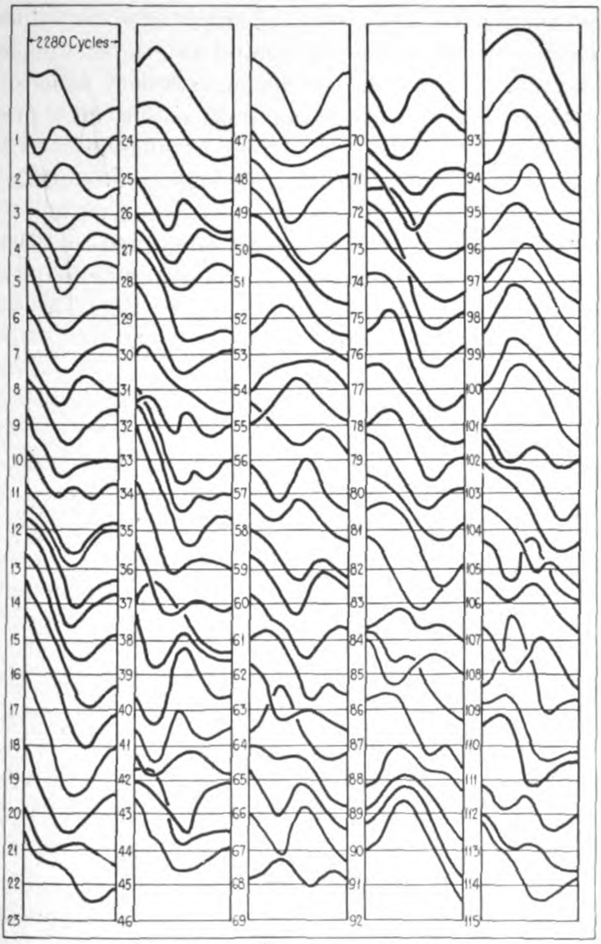


FIGURE 19—Plotted Curves, Condensing a Long Band Fading Record so as to Bring Out the Effect of Selective Fading

seems very simple at first consideration, it will be shown later to involve a particular kind of distortion which cannot be separated out as easily as the skewing encountered by the more deliberated method.

Now that we are familiar with the data, Figure 19 showing,

partially superimposed in vertical strips, the outlines of successive built-up pictures of the frequency traverse will be of greater significance. During the steady periods there appears within the 2,280-cycle band covered by these data approximately one complete cycle of selective fading. The lack of flatness in the audio frequency transmission characteristic of terminal apparatus has caused the suppression of amplitudes toward the right side of these sections. Keeping in mind also the skewing inherent to this system of presentation during transient periods, we are able to trace the movement of minima, as illustrated previously in Figure 17 which was taken from a different record. The relative position of these minima gives us an interesting insight into the nature of the night-time transmission path.

From records covering frequency ranges up to 4,500 cycles in width, the positions of major minima along the frequency axis have been plotted against time as in Figure 20. The widths of

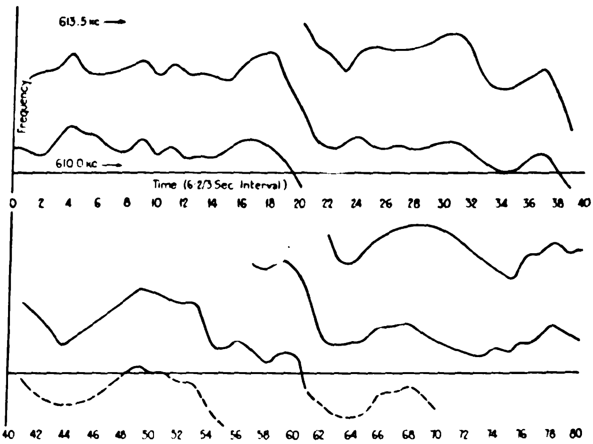


FIGURE 20—Plotted Curves which Condense a Long Band Fading Record so as to Bring Out the Frequency Spacing Interval of the Selective Fading

the frequency bands covered in this case are indicated. This picture is essentially a bird's-eye view of band fading records such as are illustrated in idealized form by Figure 18, the amplitude axis being perpendicular to the page. It reveals the presence of minima spaced at more or less definite frequency intervals, and suggests the presence of other depressions in regular spacing beyond the scope of our pictures, for when one minimum slides out of sight another appears to take its place from the opposite side of the band. The minima traces shown in broken line were outside the record but were located by extrapolating the sections.

Other depressions of small amplitude appear to be superimposed upon the major changes, but the present data appear inadequate to give reliable information concerning them. These minor depressions seem most evident during periods of rapid change.

The presence of these major minima in regular array bears a marked similarity to the familiar wave interference case in light and fits in very nicely with the theory detailed in previous paragraphs. Assume for a moment the simple case of two transmission paths producing such an effect and account for the difference in their lengths by presuming that one path follows more or less closely along the surface of the earth while the other seeks higher altitudes and in some fashion gets back to earth at the receiving station.

The mean frequency difference or spacing interval between successive minima for the records given in Figure 20 is approximately 2,200 cycles. Therefore, the mean wave length difference in length of path from equation (5) is 277 wave lengths, or 136.5 kilometers.

It is evident that the errant waves following the second path must have been led a devious route. While this is about all the information which can be deduced directly from these data it is interesting to speculate further with the information along the lines of some of the theories which have been proposed to account for such wave deflections. For instance, there is the Heaviside layer theory in which there is supposed to be a more or less well defined reflecting layer in the upper atmosphere. For this we would visualize our high altitude waves as proceeding in a straight line up to the layer, being reflected, and striking back to earth at the receiving station.

Since the distance from transmitter to receiver was 110 kilometers the length of the secondary path was 110+136.5 or 246.5 kilometers. By triangulation the height of the assumed reflecting layer may be determined as very nearly 110 kilometers or equal to the distance from transmitter to receiver, and the angle of incidence is 26.5 degrees.

As yet no positive information has been acquired concerning the variation of difference in length of two major night-time transmission paths with direct distance from the transmitter. If the path difference is due to reflection from an overhead layer, the expected relation by triangulation becomes quite simple.

$$\Delta d = \sqrt{\frac{y^2}{4} + h^2} - y.$$

When Δd is the difference in length of path, y is the direct distance and h is the vertical height of the layer.

An investigation of this relation would probably do much to prove or disprove the reflection theory.

At this point it is well to recall the results of earlier tests in which it was observed that single frequency waves separated by 1,000 cycles faded in approximately an inverse relation also indicating a spacing interval of about 2,000 cycles. The agreement of these earlier records is particularly noteworthy since about three weeks elapsed before the more detailed band fading records were made.

Figure 20 shows a time variation in the frequency position of the minima which is explained as due to a variation in the difference of path length. If we indulge in further speculation along the line of layer phenomena we conclude that the reflecting layer is rising and falling. It is improbable that the whole layer would rise and fall together, so we conclude that undulations occur along its surface. These undulations in themselves would cause the length of path of the wave reflected toward the receiver to undergo a continual change. They would also introduce minor reflections from surfaces more distant than that responsible for the major effect which may be responsible for the more rapid, low amplitude fading which is usually superimposed upon the slow changes. Obviously, the character of the fading would in the event that it is caused by undulations along the reflecting layer, be determined by the amplitude and direction of movement over the surface.

If, on the other hand, we examine the possibilities of theories such as those proposed by Nichols and Schelleng, Larmor and others in which the action of free electrons in the atmosphere is invoked, we might visualize the waves on the second path as following a curved trajectory. Or we might have the two sets of waves start off together, become split by double refraction and eventually come together again. Perhaps their planes of polarization will have been rotated. In fact, it is possible to build what appears, we must confess, to be a highly imaginary explanation in which the wave interference is accounted for not on the basis of any great difference in path length but by the assumption that the amount of rotation is such a function of frequency that a change of about 2,000 cycles adds or subtracts a complete rotation, and the further assumption that one set of waves has had its plane of polarization rotated through several more complete rotations than has the other. The synthetic

possibilities are almost endless and we must wait upon further data more varied in character before the facts can be established. In the present investigation we have not attempted to determine the mechanism of the transmission medium except insofar as it could be inferred from the results of our tests which were aimed at finding out just how radio signals look after they have been subjected to a trip through this mechanism.

Returning to the solid band fading record illustrated in Figure 18, let us form some conception of the appearance of this figure were it extended toward the much higher and lower frequencies using as a basis of this conception the supposition that the existing record is systematically distorted by wave interference. For a given rate of change in the physical difference in length of path, such as would be encountered in the simple reflection case, the rate of movement of the minima across the band fading pictures would vary directly with the frequency. Therefore, we can extend the narrow section shown in Figure 18 to form a wide band fading record such as is shown in Figure 21, wherein we are looking down upon the distorted surface, the minima being traced by the light lines. Toward the short wave end of the band it is

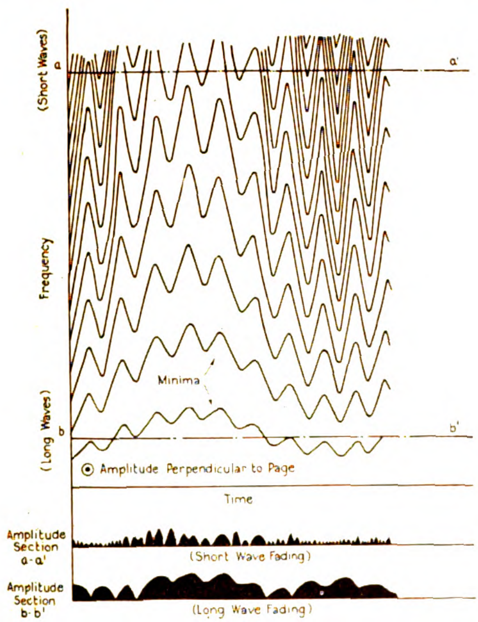


FIGURE 21—Theoretical Diagram Obtained by Extrapolating Band Fading Records to Show How the Rapidity of Fading Might be Expected to Change with the Wave Length

evident that a fading record for a single frequency represented, for example, by a section parallel to the time axis and perpendicular to the page, $a-a'$, would show rapid fading, while a similar record at the long wave end of the range as $b-b'$ would give slow amplitude changes. Such sections representing theoretical single frequency fading records are shown at the bottom of Figure 21. The relative fading rates for long and short wave lengths as indicated by these idealized characteristics, are in accord with general experience.

In describing the stepped-frequency method of obtaining band fading records, allusion was made to distortion which might result from speeding up the process. Suppose that we were to use a very small rotating condenser in parallel with the main condenser of the transmitter oscillator for changing the frequency, and that this condenser were capable of changing the frequency sinusoidally about a mean value. Then we could represent the variation in frequency with time as is shown by the curve C_1 in (a) of Figure 22. Now if the energy transfer from transmitter to receiver takes place over two paths of different lengths, one wave will constantly lag behind the other.

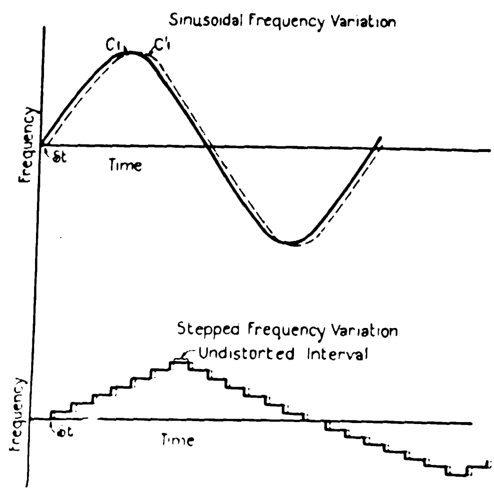


FIGURE 22—Curves Showing the Relative Effect of Transmission Time Lag in Sinusoidal and Step-by-step Methods of Frequency Variations

This lag may be measured as a time interval. In Figure 23 are shown two waves, (a) and (b) of constant amplitude but with frequency modulation. The wave (b) representing the indirect wave, it will be noticed, lags behind the direct wave represented

by (a). The amount of this lag is determined by the difference in length of path and the transmission velocity. If we were to receive only one wave, as we should in the daytime, for example, we would find it to be a constant amplitude field (providing the high-frequency characteristic of the receiver is flat over the range of frequency variation). But when two or more distinct paths exist, the combination at the receiver becomes complex. This is evident in curve (c) shown in Figure 23 which is a direct summation of (a) and (b), and in (d) which is the envelope of (c). The amplitude is subjected to variations which did not exist at all in the original wave.

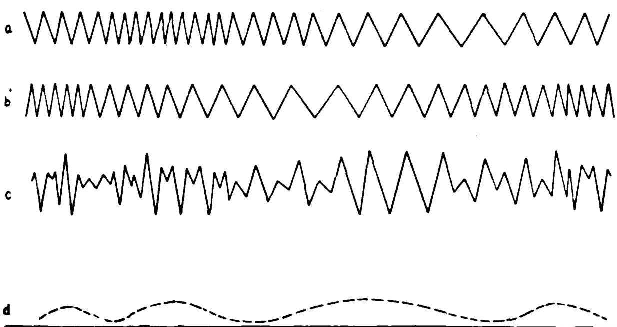


FIGURE 23—Diagram Showing the Effect of Frequency Modulation

We might set up an *equivalent* effect right at the receiver by constructing two small local oscillators having the same characteristics as the transmitter oscillator. The two small rotating condensers would be driven by the same motor, but the rotor of one would be shifted backward in phase relation to the other so as to simulate the case of transmission lag over the longer path. The relative frequency characteristics of the two may then be represented by curves C_1 and C_1' in (a) of Figure 22.

The frequency of the signal arriving over devious paths at the receiver may be put in the form of an equation as.

$$F_1 = F_o + f \sin\left[r\ (t - d_1/V)\right], \tag{6a}$$
$$F_2 = F_o + f \sin\left[r\ (t - d_2/V)\right], \tag{6b}$$

wherein,

F_o = the mean frequency
f = one-half the total variation
$r = 2\pi$ times the frequency of rotation of the condenser
d = length of path
V = velocity of waves.

For a difference in length of path equal to 300 wave lengths at a frequency of 600,000 cycles per second, for example, the time lag of one wave behind the other will be equal to 300/600,000 second or 1/2000 second. The lag of one of the condensers behind the other in the "equivalent" case described above would be then for 30 cycles per second rotation of the condensers, 30/2000 times 360 degrees or 5.4 degrees. The lag of 5.4 degrees represents the lag of the condenser rotor, so that the frequency lag will depend entirely upon the rate of change of frequency by the rotating condensers at any given instant.

Now to determine the resultant wave at the receiver we must know both amplitude and relative phase of the components arriving over the different paths. The amplitude will be constant, and we shall assume known, although it may actually follow slow changes with attenuation or variations in length of path. The relative phase must be determined from equations (6a) and (6b). Knowing the frequency variation with time we may, by integrating the following equation, determine the phase relation at any time (t).

$$\theta_1 = \int_o^t 2\pi F_1 \, dt, \tag{7}$$

$$\theta_2 = \int_o^t 2\pi F_2 \, dt. \tag{8}$$

Substituting the general relation for F_1 and F_2 from equations (6a) and (6b) we have,

$$\theta_1 = \int_o^t F_o + f \sin r \, (t - d/V), \tag{9}$$

$$\theta_2 = \int_o^t F_o + f \sin r \, (t - d'/V). \tag{10}$$

Evidently the relative phase $(\Delta\theta)$ will be the difference between these two giving:

$$\Delta\theta = \theta_1 - \theta_2 = 2\pi \int_o^t F_o \, dt + 2\pi \int_o^t f \sin r \, (t - d/V) \, dt \tag{11}$$

$$-2\pi \int_o^t F_o \, dt - 2\pi \int_o^t f \sin r \, (t - d'/V) \tag{12}$$

which integrated reduces to the form,

$$\Delta\theta = \frac{2\pi f}{p} (\cos r t - 1) \, (\cos r d'/V - \cos r d) \, V +$$

$$\sin rt \, (\sin rd'/V - \sin rd/V). \tag{13}$$

The equation is not in itself very illuminating, but what it

tells us generally is that if we represent two frequency modulated waves traveling over paths of different lengths to a distant receiver by rotating vectors, these vectors are constantly shifting their relative position. The magnitude of the shift at any instant is given by the varying angle $\Delta\,\theta$. Due to a change in the angle included by the two vectors, their resultant will undergo an amplitude change, the seriousness of which we will consider later.

Thus far in the discussion of frequency modulation by means of a rotating condenser we have assumed sinusoidal changes in frequency. The ordinary condenser departs considerably from such a performance. By considering the application of the integral equation for $\Delta\,\theta$ to such a case it will be recognized that the relative space positions of the vectors representing the direct and indirect waves will be subjected to changes at every point where the slope of the frequency-time curve departs from a simple sine relation. The degree of distortion due to the presence of such irregularities may be considerable.

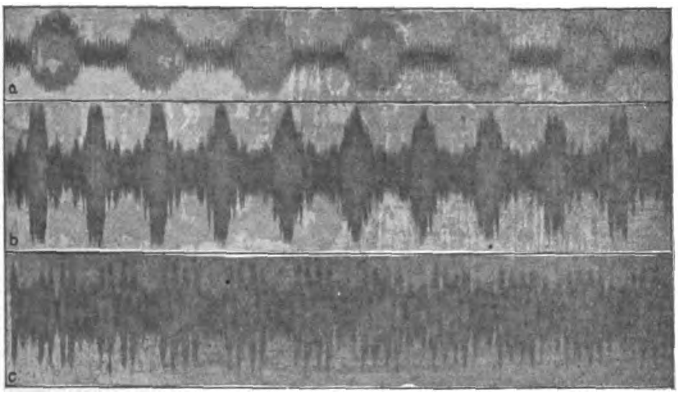


FIGURE 24—Sample Fast Records Showing Distortion Produced by Intentional Frequency Modulation. *a* Day Record, *b* and *c* Night Records

In Figure 24 are shown some samples of "wobbled" carrier frequency records obtained at Stamford, Connecticut. For these records the carrier was wobbled at the rate of about 10 cycles per second. There is some uncertainty as to the range of frequency variation for these records, although it was probably in the order of a few thousand cycles. By means of a constant frequency local oscillator the radio frequency wave was stepped down in frequency to audio values which could be amplified and recorded.

The record (a) of Figure 24 represents stable daytime reception. The record shows amplitude modulation due to the receiver characteristic alone. If the receiver were, as is desirable, capable of amplifying all the frequencies present in the received wave in the same ratio, this record would be of constant width. In the subsequent examination of night records we must keep in mind the fact that the terminal apparatus is responsible for a certain part of the amplitude modulation. Its influence is readily recognizable.

The night-time records shown in (b) and (c) reveal a distinct distortion of the envelope aside from that present in the daytime record. Peaks appear and disappear within time intervals sometimes as short as a fraction of a second.

The record in Figure 25 represents a slow picture of the changes shown in (b) and (c) of Figure 24. If these wobbled frequency waves are studied carefully it will be noted that where a single peak stands at one moment there gradually comes in view another as if it were sliding from behind the first. The cycle length being about 1/10 second we may get some idea from this series of the rate at which the changes take place. The presence of so many peaks in these records is attributed in part to the fact that the rotating condenser used gave a frequency change which was far from a simple sinusoidal relation.

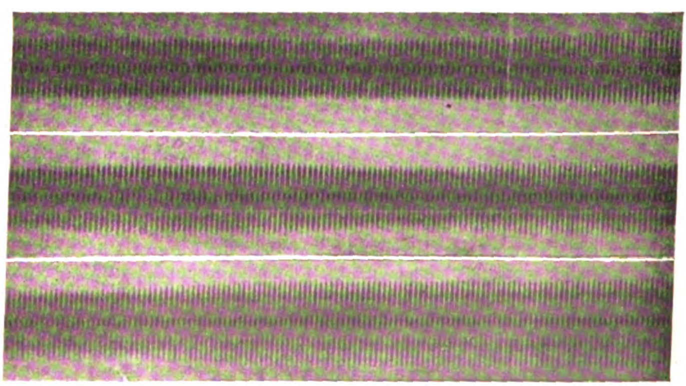


FIGURE 25—Sample Slow Record Showing Distortion Produced by Intentional Frequency Modulation. Night Record

Let us now return to the stepped-frequency method of obtaining the band fading pictures and ascertain why it has certain advantages. In (b) of Figure 22 is shown the "equivalent" characteristic for the stepped condenser. During 1/2000 of a second

(for the conditions so far assumed) in each step distortion may occur, due to transit conditions, but during the remainder of the quarter second assigned to each step (for the records so far taken) a steady state is reached. Thus, theoretically, distortion occurs only during about 1/500 of the step interval. In (b) of Figure 22 the lag is greatly exaggerated for purposes of illustration. This means simply that we have maintained constant frequency for a sufficient length of time to establish, before taking our picture, a fixed interference condition over the region including transmitter and receiver at least.

Daytime Field Strength Distribution

Thus far we have been dealing with the unstable phenomena of night-time transmission. Our interest has been directed almost entirely toward variations with time. While the presence of wave interference has been detected, and the movement of this interference effect across the frequency band has been recorded, little effort has been made to form a picture of such interference in its space relation. A discussion of similar stable, daytime phenomena is, therefore, not out of place, and particularly so in view of an evident relation of the fickle nocturnal interference phenomena to the steady states which follow the appearance of daylight.

In a previously published map of field strength distribution in New York City,* it was indicated that the congestion of high buildings just below Central Park cast a heavy shadow. More recently it has been determined from observations on a portable transmitter, set up at various points, that this building center is a consistent performer. The position of this obstruction is determined in Figure 26, wherein only partial contours from maps for the indicated sites are given to prevent confusion. The intersection of these lines from transmitter to shadow, falls at approximately 38th Street in the vicinity of Sixth Avenue.

The dissipation of wave energy at such a point is probably the composite effect of many adjacent structures. Figure 27 gives an elementary idea of how this can occur. The structures filling in each block are, of course, very well connected electrically by means of pipes, cables, etc., with those of adjacent blocks. Between each oscillating circuit (which is pictured as consisting of two buildings with earth connections), there exists a coupling which binds the whole system together more or less flexibly. Thus the obstacle offered by a group of buildings might be of a

*See footnote 1.

selective nature, and evidently its frequency characteristic may vary with direction.

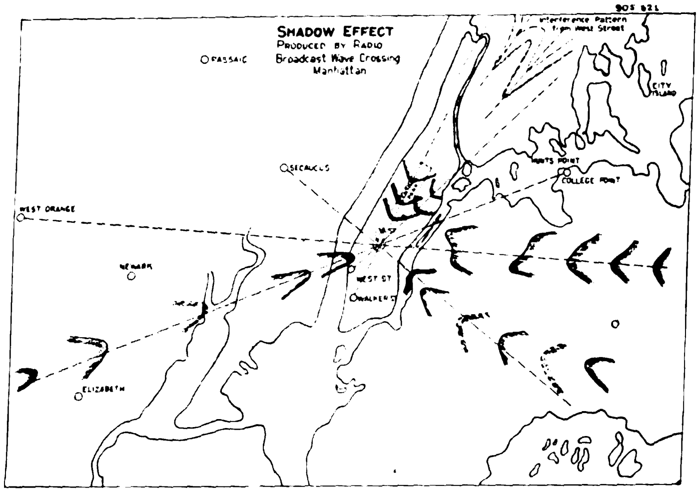


FIGURE 26—Map Showing Location of Radio Obstruction on Manhattan Island as Determined by the Intersection of Lines Between Various Transmitting Points and Their Corresponding Shadows

Such an aggregate would, in addition to absorbing wave energy, produce a change in velocity or a refraction of the wave front. Some indication of such an effect will be discussed later. Before leaving the subject of shadows, however, let us get a physical picture of their significance.

From the transmitter a wave front expanding outward and

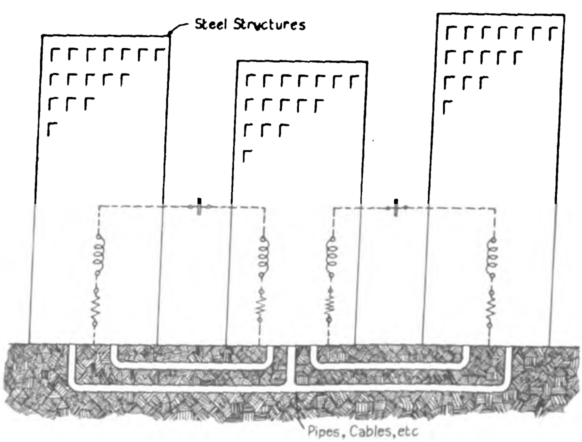
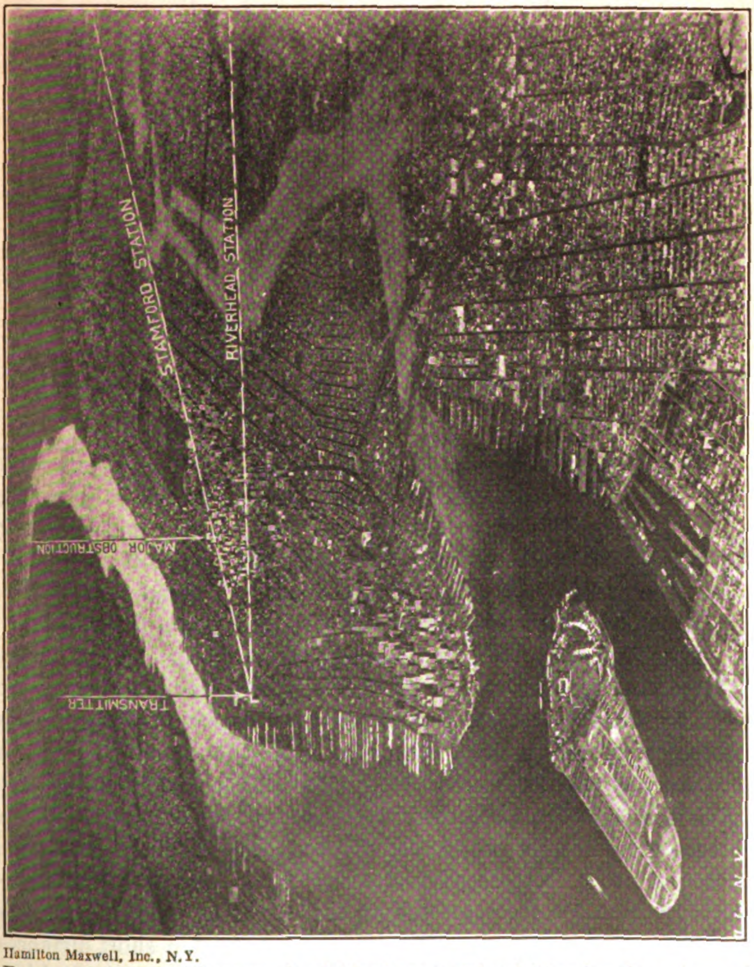


FIGURE 27—Idealized Picture of Equivalent Electrical Circuit Characterics of High Buildings

upward encounters an obstruction which we shall assume is near the earth plane. The net result of this encounter is a weakening of the wave over an area near this plane, and probably a distortion of the energy-bearing fields. We might then imagine this shadow to be a tunnel-like region extending along the earth beyond the obstruction, and as having definite vertical as well as horizontal limits.

The aerial photograph of Manhattan and adjacent territory, shown in Figure 28, will give a fairly clear idea of the conditions close to the transmitter. The major obstruction, the location of which has been previously described, is shown in its relation to



Hamilton Maxwell, Inc., N.Y.

FIGURE 28—Aerial Photograph of Manhattan Island Showing Locations of Transmitting Station and Obstructing High Building Area

the line of transmission toward the Riverhead and Stamford testing stations. Such barriers to wave travel, situated within a short distance from the source, seem, as we might expect, to have a more extensive and serious influence upon effective broadcast distribution than similar obstructions at greater distances.

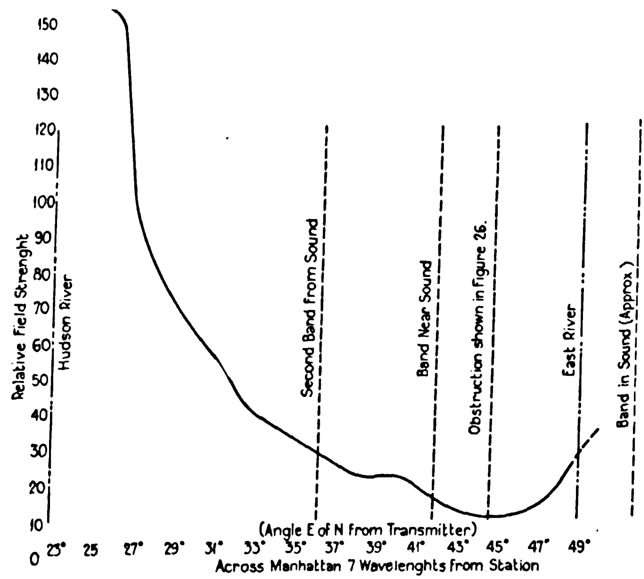


FIGURE 29—Cross-Section of Radio Shadow Caused by High Building Area

It will be noticed that the obstruction falls very nearly upon the direct line from the transmitter to the Stamford testing station. This will also be evident later after an understanding of Figure 29, wherein the position of the "Band Near Sound" represents also the bearing of the Stamford station. The Riverhead station is not directly in line with the major obstruction.

In certain sectors of the field strength contour map for station 2XB there appears to exist a kind of wavy displacement of the contour lines forming a partial pattern of peaks and depressions side by side. In general, this pattern must be differentiated from an ordinary shadow area. A remarkable example of this sort of field distribution is shown in Figure 1 which is one section of a field strength survey made for station 2XB. These contours are based entirely upon daytime measurements, and represent a condition which is stable throughout the daylight period. Considerable difference in signal level is apparent within short distances across the direction of wave propagation. Two pronounced low

signal channels extend approximately northeast across this region. These shift with change in frequency of the transmitted wave. Figure 30 illustrates the space relations for such a movement. The full line curve shows a partial cross-section of the contour map of Figure 1 taken along a line approximately perpendicular to the direction of transmission 110 wave lengths from the transmitter. This represents relative field strength values for 610.0-kilocycle radiation. When the frequency is raised to 635.0 kilocycles, there occurs a movement of the peaks and depressions as is shown by the broken line of Figure 30. Apparently the increased frequency causes these channels to be crowded together.

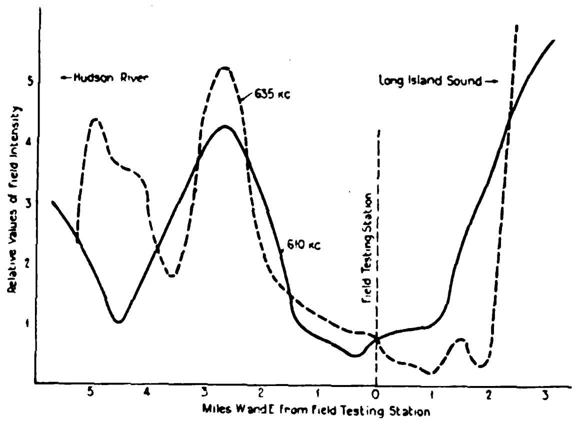


FIGURE 30—Cross-Section of Wave Interference Pattern Showing Change With Frequency

If we take sections of the field strength contour pattern in Figure 1 and examine carefully the relative amplitude of peaks and depressions represented by these wavy lines, we shall find that the ratio of field strength of the peaks to that in the depressions increases with distance from the transmitter. That is, the channels become more sharply defined as we move away from the transmitter. This ratio is shown approximately by the curves of Figure 31. If these peaks or depressions were simple shadows they would maintain their relative values at a distance from the source or even tend to "heal," causing the ratio to fall rather than rise as is actually the case.

Within 14.4 wave lengths (7.1 km.) of the transmitter the pattern so apparent beyond 30 wave lengths merges into one deep shadow a cross-section of which is shown in Figure 29. The

abscissa of this curve is in degrees measured from the transmitter so that the center of the two most distinct low field strength channels extending northeast may be inserted with their true radial relation. The two most evident in Figure 1 are shown to be west of the line extending from transmitter through the center of obstruction located in Figure 26. The presence of Long Island Sound east of the geometrical center of the shadow has made an extensive survey of this section impractical. However, a single section taken across the Sound at about 90 wave lengths from the station shows quite unquestionably the presence of a low channel about as indicated to the right of the obstruction designated in Figure 29.

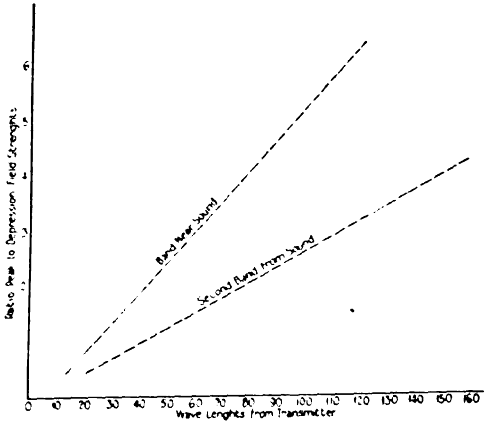


FIGURE 31—Plot Showing Intensity of Definition of Wave Interference Pattern

We have, therefore, a deep shadow with a more or less orderly array of maxima and minima within its limits. These maxima and minima grow more distinct at a distance from the transmitter, contrary to what we might expect for ordinary shadows. Furthermore, we find that they move as the frequency is changed. These facts lead to the belief that the phenomena in question are due to wave interference such as has already been described in connection with night-time fading, but characterized by very much smaller path differences. This daytime interference condition is fixed while we have seen that the nocturnal patterns appear to wander continually. To explain this more in detail let us return to the shadow and consider the phenomena which might accompany it in a little more detail.

The study of light has made available much information concerning the subject of wave interference. It is known, for in-

stance, that the edges of shadows are not sharply discontinuous changes from light to darkness, but that a series of dark and light bands, called diffraction fringes, are interposed between the full light and full dark areas. In our radio case, the distance from the source to the obstruction and the dimensions of the obstruction are both very much smaller, in comparison with the wave length of the radiation, than for any ordinary case in light, but apparently the phenomenon is of the same general nature. By applying the ingenious principle of secondary sources used by Huyghens, we might theoretically determine the distribution of the field beyond an obstruction placed in the path of the advancing radio waves. The basis of this principle is the assumption that each elementary part of the advancing wave may be considered as a tiny transmitter. The effect at any point behind an obstruction, therefore, becomes the resultant effect, considering phase as well as amplitude, of the waves from all these miniature sources.

In Figure 32 the region between vertical lines (a) and (b) represents the geometrical limits of the cross-section of a well-defined shadow taken some distance behind the obstruction.

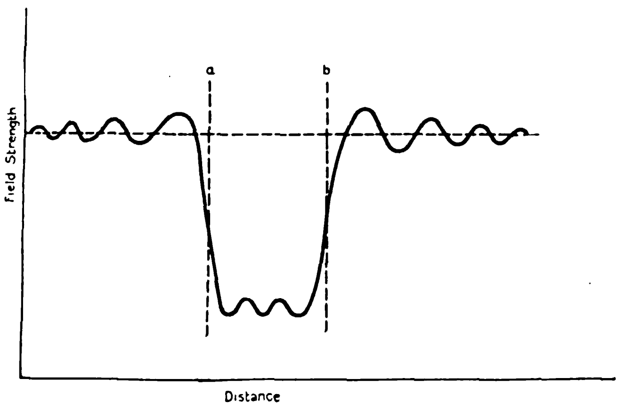


FIGURE 32—Theoretical Cross-Section of Radio Shadow and Associated Wave Interference Pattern

An analysis of the resultant field using Huyghens' construction would show variations in intensity somewhat as represented by the full line. In other words, the shadow will not be distinct, but will have alternate maxima and minima within its geometrical limits and similar variations beyond the edges.

It is very likely, of course, that even in case the foregoing speculative analysis of the contour pattern extending northeast of 2XB is fundamentally correct, a great many other influences

than that of obstruction enter into the final field distribution. Relative attenuation of water and land appear to influence the distribution considerably though not as definitely as do steel structures close to the transmitter. Distinct minima appear both on the Hudson and on the Sound along radial lines extending from the transmitter.

Probably refraction of the wave front in passing across shore lines also enters into the shaping of this pattern.

Perhaps as good an elementary picture as any of the phenomena causing these patterns is that of a "dent" produced in the wave front by an encounter with a portion of New York City's impressive skyline. Since radio waves travel in a direction perpendicular to the plane containing the electric and magnetic fields, opposite sides of this "dent" would cross over one another with the result that an interference pattern would appear beyond the obstruction. An analogous situation exists when a water ripple passes a cluster of marsh grass which, damping its motion and retarding its progress, causes part of the advancing front to converge and cross beyond the obstruction.

There is evidently a relation between day patterns such as have been discussed and night-time conditions. Just what this relation is offers some further opportunity for conjecture. In the first place, quality distortion in transmission at night was, as previously explained, observed over parts of the region covered by the pattern shown in Figure 1. The worst distortion seemed to be somewhat associated with the low field strength regions in this daylight survey. The distortion seemed also to be worse along the low channel extending in the direction of New Canaan, Connecticut, and beyond the 100-wave-length circle. It was parricularly bad at a distance of some 140 wave lengths from the station along this low channel where the field strength became so low in the daytime as to be unmeasurable with the set employed for the work. Accompanying the poor quality were fading and marked directional shifts.

Quality distortion, though not so consistently severe at the Riverhead station as in the vicinity of Stamford, was at times easily detectable by audible tests. Due to rapid attenuation of the radio waves traveling from the site of 2XB across Manhattan and the length of Long Island the field strength around Riverhead is generally low with higher levels north and south on the open waters of the Sound and Ocean, respectively. Night-time fading at this point was representative of the variety which is

usually found at distances of approximately one hundred miles from a broadcast transmitter.

The situation at Riverhead appears to be somewhat the same as that which may exist over a large part of the broadcast area at a distance from the transmitter, while in the Westchester region we have an extreme and rather special circumstance. Field strength surveys have shown that there are indications of a daytime interference pattern over the Riverhead area, but this pattern, such as it is, appears to be irregular and to lack the definition which makes the Westchester pattern so remarkable.

On the basis of the Westchester data alone we might build up a theory to the effect that night-time shifts of the stable daylight pattern were in some way responsible for quality distortion following the departure of daylight. Such a thought applied to the Riverhead case does not seem so reasonable, since here the pattern is about one-quarter as distinct in terms of the ratio of maxima to minima values as the Westchester pattern. If, however, we presume that quality distortion may be expected in areas where daytime signals arrive *considerably attenuated*, or so interfering as to simulate such an attenuated condition, both situations are satisfied. After a consideration of the evidence at present available, such a conclusion seems attractive; that is, a daytime wave interference pattern alone is only an agency in night-time quality distortion, in so far as its minima in combination with the general shadow effect are responsible for a low signal *directly* transmitted. Perhaps, in other words, the daytime field strength is a measure of *direct* night-time transmission, there existing in combination with this direct path at night a second, variable route of greater effective length. Probably close to the transmitter the "direct wave" is large compared to the "indirect," but shadows or interference may materially modify the ratio.

Night Distribution of Field Strength

By receiving simultaneously at several points the signal coming from a distant transmitter, it ought to be possible to detect the movement in space of these interference bands we have been discussing. The question immediately arises as to how far apart these distributed receivers can be placed without giving us an entirely discontinuous and misleading picture. For the first step toward recording space variations, in the vicinity of the Riverhead testing station, the receivers were spaced 1/16 wave length (30.5 meters), as illustrated in Figure 33. It is necessary in making

such determinations to transmit a single radio frequency, since we have already found that the interference bands for one component of a modulated wave are likely to be in a different position than those for another.

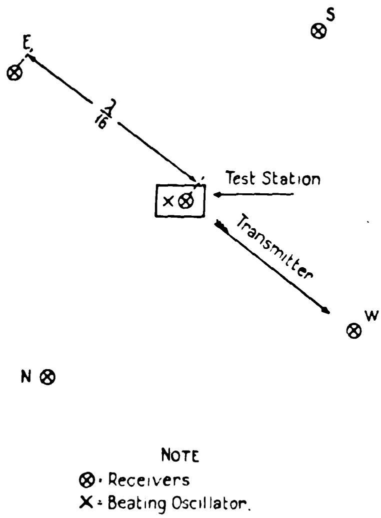


FIGURE 33—Diagram Showing Space Relation of Receiving Sets for Special Test

In order to receive and record the radio frequency wave it is, as has already been shown, convenient to use a local oscillator to beat it down to audible values. Since several oscillators for the separate sets are likely to produce mutual interference a common one was employed. This beating oscillator was situated at the testing station and the receiving antenna at this point was used as a radiator. In order to prevent overloading, the local receiver, the coupling to the receiver input coil, was balanced to give a minimum of the local signal.

Figure 34 is a sample of the record obtained. The continuous shadow band at the top represents the local receiver output. One oscillator element was used for the other four receivers, their signals being recorded successively by the commutating device. Incidentally the interaction between these receivers was checked by observing the output of any one, while changes were made in the tuning of the others. The antenna was, however, so nearly aperiodic that no recognizable distortion or reradiation phenomena could be detected.

Figure 35 illustrates compactly variations recorded by the

oscillograph records (of which Figure 34 is a sample), for a representative period of about five minutes. Even within the dimensions of 1/16 wave length there appears to exist transient field strength gradients in the direction of transmission. This is

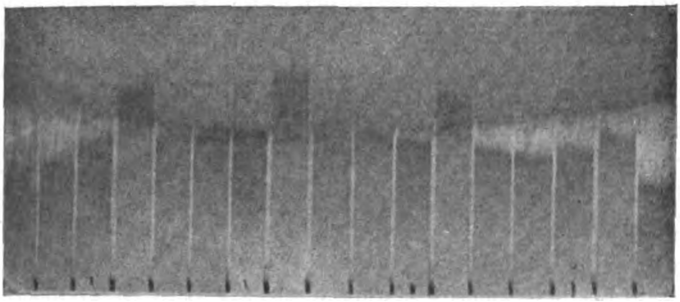


FIGURE 34—Sample Single Frequency Fading Record from Spaced Receiving Sets

shown by a change in relative values, in the upper set of curves which represents field strength at points 1/16-wave length apart in the direction of transmission. The deviation is particularly noticeable in the relation between values for the local receiver and the "West receiver" which is in the direction of the transmitting station.

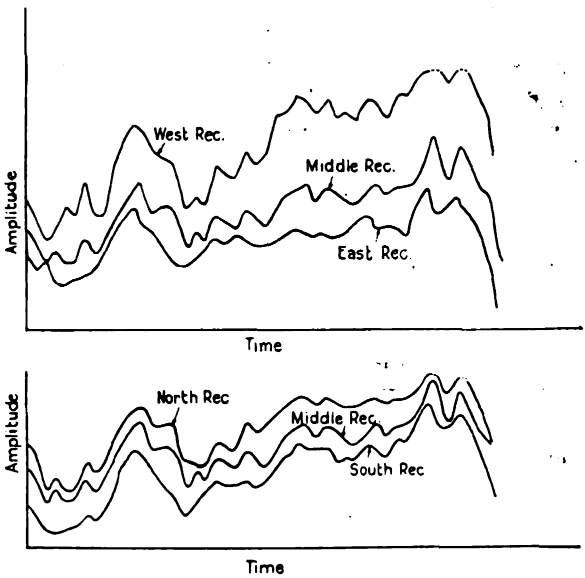


FIGURE 35—Curves Showing Single Frequency Fading on Spaced Receivers, Condensed from Long Record

The lower set of curves, representing similar values across the line of transmission are much more nearly parallel. From the data so far obtained for the Riverhead testing site, it seems that transient night-time field strength gradients are more generally evident in the direction of transmission than perpendicular to this direction. Upon these limited data one might be tempted to predict the presence of interference bands across the line of transmission.

The above discussion concerning space relation of field strengths has been included merely by way of contributing an additional bit of evidence to the theory that the erratic type of fading ordinarily experienced at night is due to wave interference. The picture is very small in terms of wave lengths but considering its content, its very limits seem to imply wave interference rather than attenuation alone.

In connection with the wave interference theory thus far suggested as responsible for a major part of fading, Figure 36 is introduced as added evidence. The middle record of this group represents amplitude changes in the night-time reception of a carrier wave upon a vertical antenna. The upper and lower records represent the same for two loops turned at right angles to one another in the horizontal plane. By daytime tests the interaction of this combination was found to be negligible. Night-time fading recorded simultaneously for these three separate receivers occupying as nearly the same point in space as was possible, show that a high-amplitude signal may be coming in on both loops while the vertical antenna pick-up approaches zero. Several points of this kind are marked by arrows below the middle trace in Figure 36.

There are at least two simple possibilities which might account for these relations. In case the wave approaches the receiving point from directly overhead, the vertical antenna would receive a "zero" signal while the loops would pick up an amount depending upon the state of polarization. If this be true, the records indicate a very rapid shift from the vertical direction of reception since the antenna minima are short lived, most of them lasting at best a small fraction of a second.

On the basis of wave interference it is apparent that two waves approaching the receiving point in a 90-degree space phase relation and 180 degrees out-of-time phase could give a maximum signal on the two loops while that received on the vertical antenna was a minimum.

A compromise between these two viewpoints is probably a

better guess than either one of them taken alone. That is, the existence of minima on the vertical antenna at the same moment that a strong signal is coming in on the loops is perhaps due to the interfering combination of waves having components in both the vertical and horizontal planes.

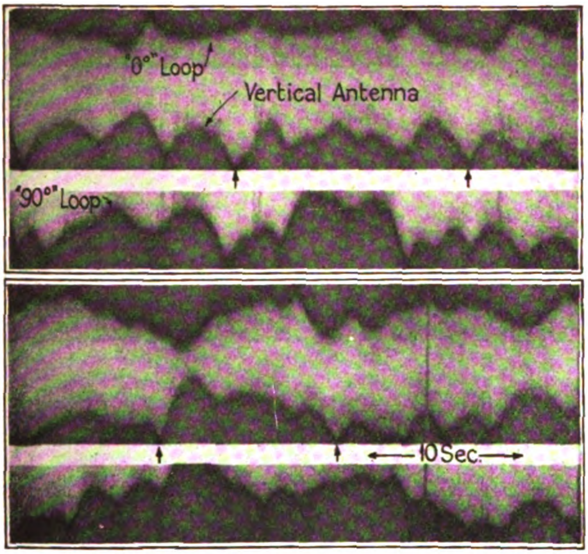


FIGURE 36—Single Frequency Fading Record from Vertical Antenna and Two-Loop Antenna Crossed at Right Angles

QUALITY DISTORTION

So far the data shown have been limited to the results of observations taken on special forms of transmission which are simplified for the purpose of clearly exposing the basic facts. We wish now to consider some of the more practical aspects of signal distortion. The first test which we made at our field test station was to record on slowly moving photographic paper tape and on the high speed film, the detected audio signal which resulted when the transmitter was modulated by a pure 264-cycle tone.

Figure 37 is a sample of the general type of audio signal record obtained and Figure 38 shows copies of the wave shape of the received signal, at particular times corresponding to the numbers of the oscillograms on the records in Figure 37. The abrupt displacement of the timing trace indicates the point on the long record at which the snapshot oscillogram was made.

A peculiar characteristic of these records is the dark shadowy lines weaving back and forth through the band recording the complete signal. These dark lines correspond to the kinks in the wave shape shown in Figure 38. As explained before, the dark-

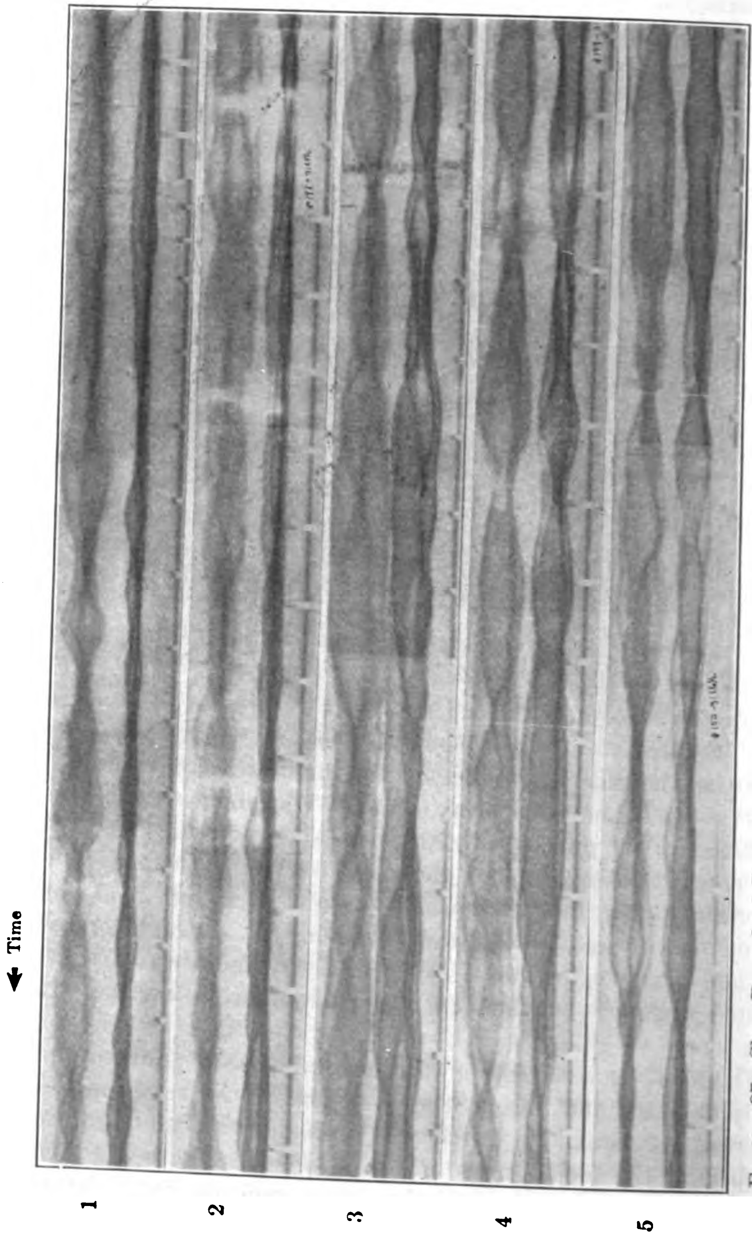


FIGURE 37—Slow Record of Signal Detected from Tone Modulated Transmission, Showing the Night-time Distortion. Made at Stamford, Conn., May 15, 1924, 2.25 A. M. Upper Trace Signal from Vertical Antenna Receiver and Lower Trace Signal from Loop Antenna Receiver, Timing Marks 2.6 Seconds Apart

ening of the record is caused by the greater quantity of light affecting the record at these peak points. At the same time these observations were made, the wave shape of the signal rectified from the antenna current at the transmitter was recorded by an oscillograph. These oscillograms showed the signal to be free from distortion at the transmitter.

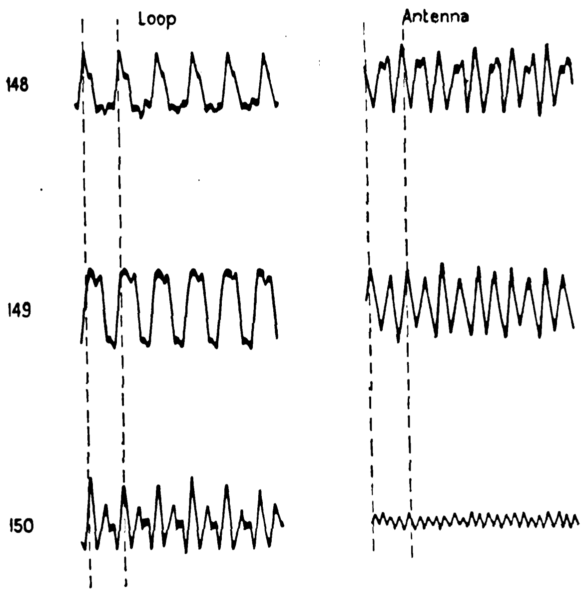


FIGURE 38—Wave Form of Signals Corresponding to Numbered Positions Indicated on Strips 2, 4, and 5, Figure 37

The weaving of these shadowy traces, together with their width gives a record of the change in phase and amplitude of the irregularities in the wave shape of the signal. Although the wave shape of the signal is continually changing, it persists in substantially the same form for a great many cycles. Thus the record shows that, in the transmission of this simple tone modulated signal from the transmitting to the receiving antenna, it has been so modified that entirely new frequencies appear at the receiver. This receiver was shown by local tests to be free of any appreciable distortion within itself. While these new frequencies look like harmonics of the modulating tone in the snapshot record it is obvious from the slow record that they are not true harmonics but that they differ from the harmonics by a very small amount and are incommensurable with the modulating tone since they undergo progressive but irregular phase changes with reference to it.

These records represent in a nutshell the signal distortion problem as it first presented itself to us. Our work then consisted in raveling out the complicated relations so that their nature could be ascertained and a theory of the causes established. In this paper, in the interest of clarity of presentation, we have departed considerably from the actual order of the experimental work, but at this point perhaps the actual order is best to follow for a moment.

With such a weird-looking distortion to analyze, and if possible eliminate, our first thought was as to whether the terminal apparatus might not involve unrecognized peculiarities which would be a contributing cause. Local tests and daytime tests of the receiving system absolved it from doubt and attention was focused on the transmitting apparatus.

It was suspected that present day radio telephone transmitters leave something to be desired in regard to what we may call, for lack of a better term, their dynamic frequency stability. A very large percentage of the transmitters in use throughout the world today produce amplitude modulation of the carrier by the action of modulating tubes directly upon an oscillating tube circuit. It is to be expected that the cyclic changes in circuit conditions occurring at the modulating frequency will have some cyclic effect on the absolute frequency of the carrier and that this effect will be in the nature of a wobbling or rapid shifting back and forth in frequency of the amplitude modulated carrier. In other words, the carrier and side bands, without change in their relative frequencies, would be subjected to "frequency modulation."

This sort of thing should be clearly distinguished from the slow wandering of frequency which, for instance, causes beat notes between carriers of different stations to drift gradually in pitch. What we have called "dynamic instability" is so rapid (being governed by the cyclic variations of the modulator) that it is difficult to observe by any aural method. Since the transmitter being used for our tests was a member of this almost universal class which employs modulating elements directly associated with the oscillator elements we determined to study this aspect of the transmission.

The following test was made to find out the extent of the frequency variation during the period of the modulating cycle. A schematic diagram of the testing circuit arrangement is shown in Figure 39. The plan was to modulate the carrier with 33 cycles, a tone so low in frequency that it would not be efficiently

transmitted through the audio frequency amplifier connected to the output of the radio receiver. Then upon beating the received modulated carrier signal down to a frequency of about 1,000 cycles, an oscillogram of this signal would show a 1,000-cycle signal with a 33-cycle modulation in amplitude. Frequency

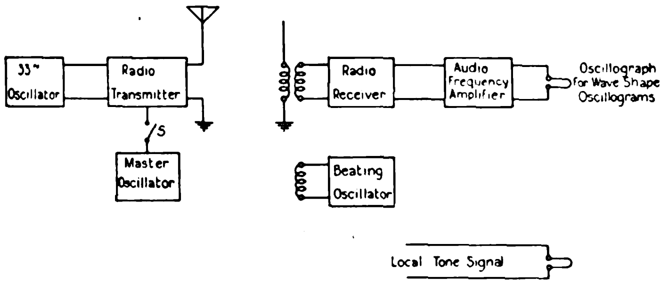


FIGURE 39—Diagram of System Used to Measure Frequency Modulation

modulation, if present, should then be easily discernible from the record. This experiment was made for daytime transmission, and oscillograms (A) and (B) shown in Figure 40 were obtained, one with the frequency of the beating oscillator greater than the carrier frequency, and the other with the beating oscillator frequency less than the carrier frequency. Both of these oscillograms show by the change in the frequency of the beat note signal that frequency modulation occurs in the transmitter circuit. The frequency change is very apparent on the oscillograms when the lengths of one cycle at maximum and minimum amplitudes are compared. The reality of the effect is demonstrated in the two records, which by their difference show the reversal of the increased and decreased frequency points with reference to the modulation cycle when the beating frequency is moved in frequency from one side of the carrier to the other.

The next step was to determine to what extent a stabilization of the carrier frequency to stop frequency modulation would affect the distortion of signals. True, master oscillator transmitters capable of giving the desired stability are not a new thing in the art. Several such transmitters were built by the Western Electric Company some years ago and used successfully in ship-to-shore radio telephone experiments [2] in which frequency stability was of considerable importance. To modify the ordinary

[2] See Figure 1 and accompanying discussion in: "Radio Extension of the Telephone System to Ships at Sea," by H. W. Nichols and Lloyd Espenschied, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 11, number 3.

broadcasting transmitter to include this feature involves major mechanical changes, and in order to provide a suitable arrangement for these tests the Bell Telephone Laboratories engineers merely added to the existing transmitter at station 2XB a temporary separate oscillator and high-frequency amplifier which could be connected to drive the oscillator tubes of the set as amplifiers. That this was free from frequency modulation is seen by comparing (C) of Figure 40 with (A) and (B).

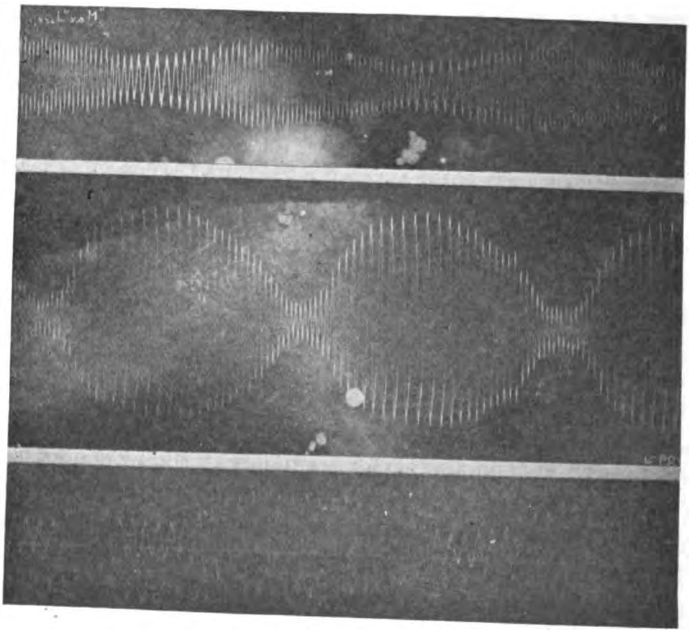


FIGURE 40—Oscillograms Showing Frequency Modulation Accompanying Amplitude Modulation

The transmission tests carried out with this arrangement yielded highly satisfactory results as indicated by a comparison of Figure 41 with Figure 37. Figure 41 like Figure 37 is the detected result of a signal which started from the transmitter as a pure tone modulated signal, but it shows that much of the wave form distortion has disappeared, there remaining only a residuum which characteristically appears at the lower amplitudes of the signal. The probable cause of this residual effect will be discussed later. Tests of speech and music were concurrent with these findings. Using the normal transmitter, night-time transmission as received at the test stations was

seriously distorted. When the stabilizing arrangement was employed, this distortion was apparently eliminated except at the minima of fading.

Having arrived, then, at this practical result we wished to make further confirming tests, and tests to determine the whys

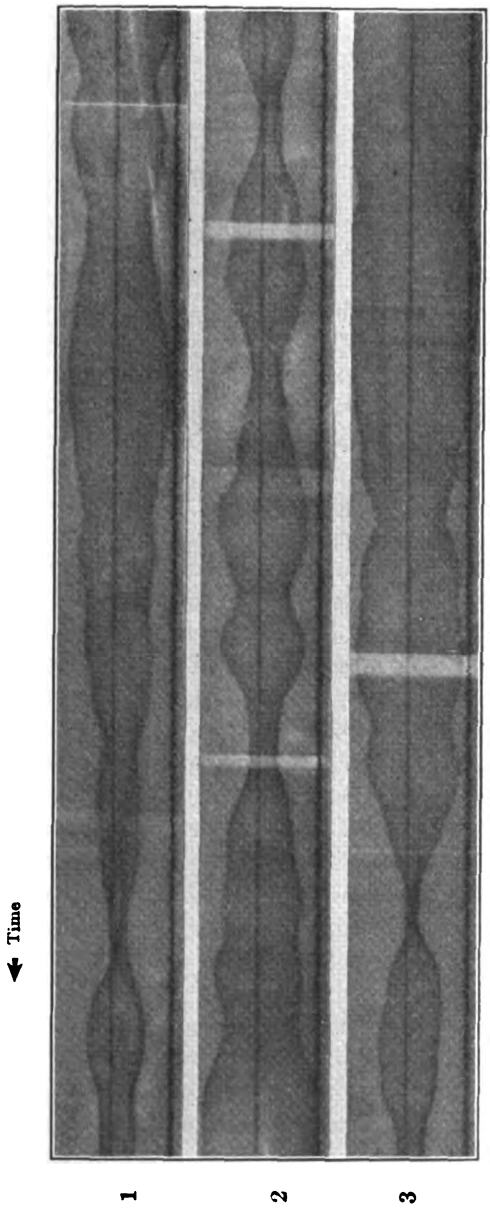


FIGURE 41—Slow Record of Signal Detected from Tone Modulated Transmission with Stabilized Carrier Showing Reduction in Distortion. Made at Stamford, Conn., Oct. 10, 1924, 3 A. M.

and wherefores of the result. We have already detailed the more basic of these tests in previous sections of this paper and are now ready to consider the practical distortion records more carefully and to build up a theory to explain them.

The records shown in Figure 42 are similar to the records in Figure 37. They are shown here to illustrate the difference in the characteristics of the wave form distortion variation that occurs from day to day. All these records were made at Stamford, Conn.

Strips 1 and 2—May 15, 1924—4:30 A. M.
Strips 3 and 4—Jan. 23, 1925—5:30 A. M.
Strips 5 and 6—Jan. 24, 1925—6:15 A. M.
Strips 7 and 8—Jan. 24, 1925—8:00 A. M.

There is a marked difference in the records obtained on January 23 and 24, which were made at the time an effort was being made to determine the effect of the solar eclipse on radio transmission. The peculiarly twisted appearance of the record obtained on January 24 is not very common in the records obtained. Most of the records have characteristics similar to those shown in Figure 37. In the January 24 records there is a marked change in the characteristic configuration of the variation.

In order to obtain a record of the amount of wave form distortion resulting from frequency modulation present in the detected audio signal the circuit arrangement shown in Figure 43 was used. This circuit was designed to analyze the wave form distortion when a 250-cycle signal was used to modulate the carrier. Special precautions were taken to obtain a pure 250-cycle modulating tone. The wave shape of the signal detected from the carrier at the transmitter was frequently checked by observations with an oscillograph. The signals detected from the antenna current at the transmitter, both for the normal transmitter with frequency modulation and for the stabilized carrier transmitter, were practically simple sine waves. The output circuit of the radio receiver was connected to a group of filters designed to transmit narrow bands of frequencies straddling the harmonics of 250 cycles.

While below we have referred to the frequencies passing these filters as "harmonics" it should be borne in mind that they are not necessarily *true* harmonics since they deviate very slightly from the true harmonic relation. The purpose of the test was to procure a record which would show at a glance the presence or absence of wave form distortion.

The input circuits of the filters were connected in parallel and the output circuits separately connected to the audio amplifiers arranged to operate the oscillograph elements. The input of one amplifier was arranged so that it could be switched either to the

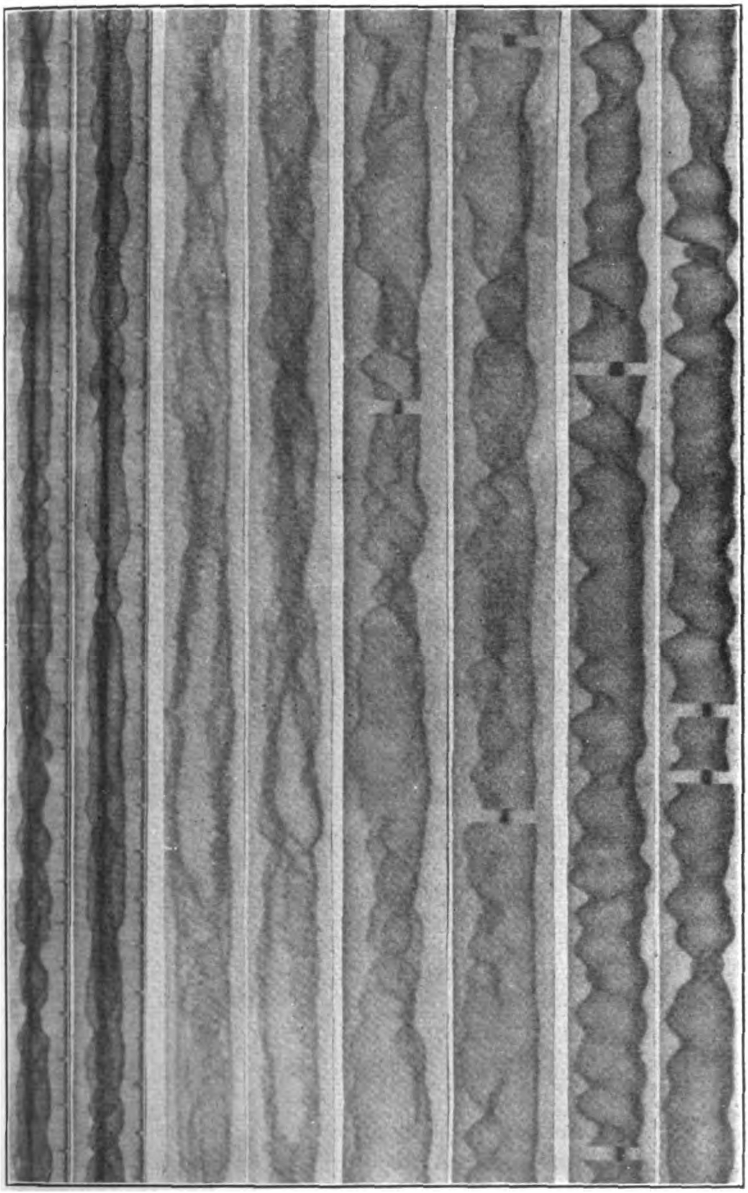


FIGURE 42—Slow Record of Signal Detected from Tone Modulated Transmission Taken on Different Days Showing the Changes in the Character of the Distortion

output of the filter passing 250 cycles or the output of the radio receiver. In this way a record could be obtained of either the whole tone from the receiver or only the 250-cycle component.

In Figure 44, strip 1 is a harmonic analysis record of the audio tone detected from the carrier and both side bands, transmitted with a stable carrier frequency. Strip 2 is a section of a record made a few minutes later when an unstabilized carrier was being used. On this record the lower trace is the 250-cycle component, the center trace the 500-cycle component, and the upper trace the 750-cycle component. The upper and lower traces have their zero lines at the edges of the strip. This record

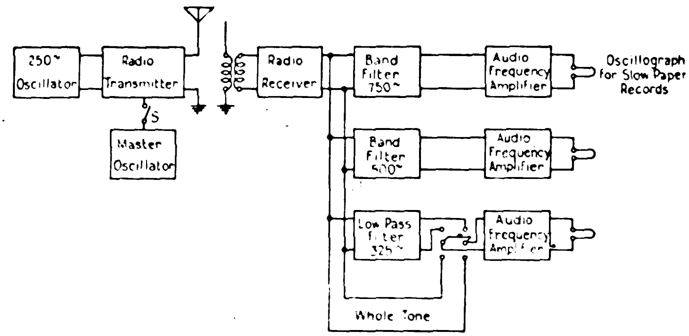


FIGURE 43—Diagram of System Used to Obtain "Harmonic" Analysis Distortion Records

was made at Riverhead, L. I., April 30, 1925, at 3:33 A. M. Strip 2 is a section of a record made a few minutes later when an unstabilized carrier was being used.

The gain in the audio amplifiers connected to the outputs of the filters was adjusted to give nearly uniform transmission through the receiving and recording apparatus for the frequencies recorded. Hence in these records the relative amplitudes of the fundamental and harmonics of the signal are directly comparable.

Strips 3, 4 and 5 in Figure 44 are taken from a record made for the purpose of obtaining a comparison of the wave form distortion sustained by the detected audio signal transmitted by the normal transmitter with frequency modulation present and by a stable frequency transmitter. In each strip the lower trace is the whole tone from the output of the radio receiver, the middle trace the second harmonic (500 cycles) and the upper trace the third harmonic (750 cycles). Strip 3 and half of strip 4 give the record obtained when the normal transmitter was used, and the remainder is the record obtained when the modified

transmitter was used. There was a few minutes' difference in time between the ending of one transmitting condition and the beginning of the next, during which the master oscillator control was switched on at the transmitter. The receiving circuit was

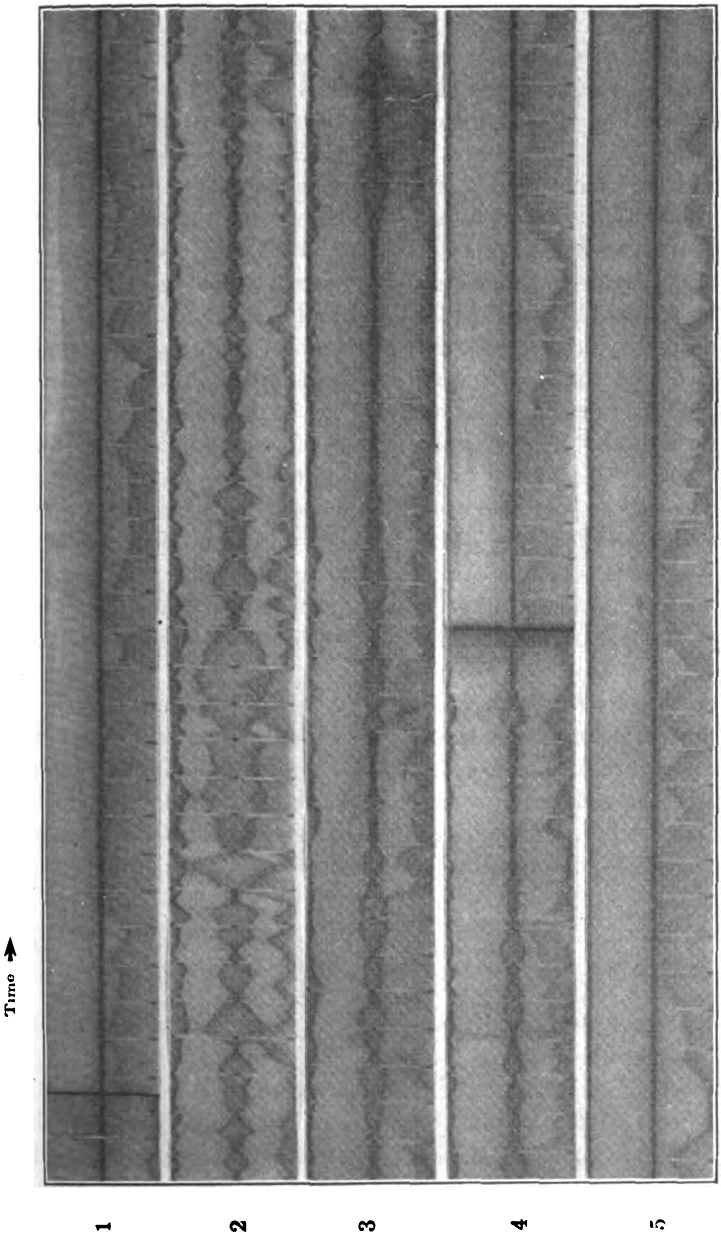


FIGURE 44—Slow Record Made with System Diagrammed in Figure 43. Contrasting the Distortion of Detected Tone Transmitted by Stabilized and Unstabilized Carrier Frequency

not changed during the making of this record, so that the results obtained from the two transmitters are directly comparable.

The record of the signal from the normal transmitter shows an abundance of second and third harmonics, at times equal in amplitude to that of the whole tone signal. The latter, of course, includes these harmonics. It will be noted also that dark line shadows run through the trace of the whole tone, indicating the presence of the wave form distortion. The signal from the stable frequency transmitter as shown by the record is practically free from wave form distortion. The trace of the whole tone is also free from any dark lines which would indicate wave form distortion. This record is substantial evidence that a great deal of the wave form distortion may be eliminated when the carrier is stabilized. However, the selective fading still remains.

The selective fading we have already explained more or less satisfactorily and we find that it does not materially affect the wave form of audible frequencies transmitted by a modulated stabilized carrier unless its changes are more rapid than any we have recorded. The crippled state of originally perfect tone waves after they have been transmitted by an unstabilized carrier, we have just observed. Now let us consider the possible causes of this difference. The carrier stabilization referred to here, may we repeat, is not stabilization against slow variations in frequency from second to second or from hour to hour, but rather against rapid variations within the cycle of the modulating frequency.

The reason for such changes over the modulating cycle is that the variation of the impedance of a vacuum tube across the oscillating circuit necessarily causes a variation in the nature period of the oscillation. As a simple case, the circuit in Figure 45 is given. H. J. Van der Bijl in his analysis[3] of this circuit gives the natural frequency of oscillation as

$$n = \frac{1}{2\pi}\sqrt{\frac{\left(1+\frac{r}{r_p}\right)}{L_2 C}} \tag{14}$$

when r_p is the plate resistance and the remaining constants are given in the illustration.

Direct modulation by the usual method involves a cyclic change in the value of plate resistance. Hence, according to the above equation, there results a cyclic change in frequency which, though relatively small, becomes of the utmost importance

[3] "Thermionic Vacuum Tube," by Van der Bijl, page 274.

when subjected to the peculiar phenomena of night-time transmission.

By making certain assumptions concerning the nature of frequency variation as amplitude modulation takes place, it is possible to work out distorted waves corresponding to various assumed wave interference conditions at the receiver. Perhaps the most simple and instructive means for producing these distorted waves is by a graphical method.

The equation for modulation of a high-frequency wave by a single tone may be written

$$e = (A + kA \cos vt) \sin pt \tag{15}$$

When A represents the unmodulated amplitude of the wave, k is a factor determined by degree of modulation, v is an angular

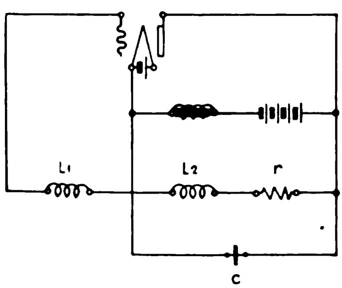


FIGURE 45—Diagram of an Oscillator Circuit

velocity of the tone wave and p is the angular velocity of the high-frequency wave. The amplitude factor in this equation may be considered as a vector which is undergoing a change in length in accordance with the term included in the brackets. For the purpose of our analysis we shall include the angular velocity imparted in this vector by the last term in the above equation, since we are interested in the envelope of the resultant high-frequency wave at the receiver and the relative phase relations for two waves directly and indirectly transmitted combining to form this resultant. Since both carrier waves are of the same mean frequency, only the relative position need be considered.

Now in our graphical determinations for the case of two transmission paths different in length, we represent the two effective fields by vectors varying in length in accordance with the amplitude factor of equation (15). However, due to the

difference in length of path, the changes in length of one vector will *lag the changes in length of the other* by any amount

$$\phi = v\ (\Delta t) \tag{16}$$

when Δt equals the difference in time of transmission over the two paths and v is the angular velocity of the modulating tone. This angle ϕ for 500-cycle modulation may, according to the data thus far described, amount to more than 90 degrees at the receiving points selected for observation.

In addition to the lag in amplitude there will be a lag in frequency change over the frequency modulation cycle. This lag,

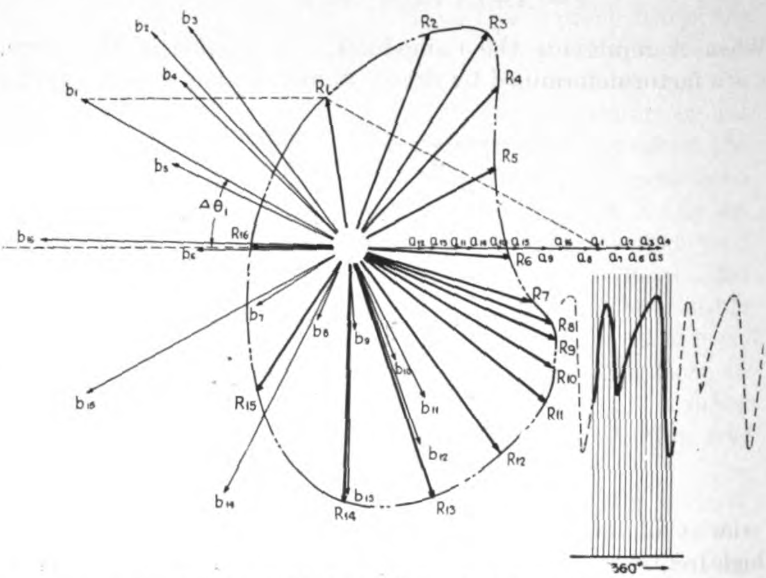


FIGURE 46—Graphical Method of Synthesizing Distorted Wave Forms Caused by Frequency Modulation

which has already been shown in connection with the analysis of distortion in certain types of band fading records (see Figure 22), becomes *a change in the relative phase angle* of the vectors under consideration. Thus our picture finally becomes one of two vectors changing in length, the changes in one continually lagging the changes in the other, the two vectors at the same time undergoing what we might term a relative angular wobble.

In Figure 46 these relations are produced graphically. For our purposes we might assume that the vector representing one field is fixed and allow the other one to wobble the relative amount. At an instant, for example, the directly transmitted

field may be represented by a_1 in this figure. Assuming a difference in length of path, we may compute on the basis of the integral equation (13), the relative phase position of the vector representing the indirectly transmitted field b_1. The relative amplitude of this vector may also be determined by substituting $\Delta \phi$ in equation (15).

After establishing a sufficient number of vectors to represent the cyclic variation, we may combine the respective components to obtain the resultant representative of the successive instants. These are shown as R_1, R_2, R_3, etc., a broken line being drawn through their extremities to identify their positions. Now, if we plot these resultants as vertical ordinates in their successive time

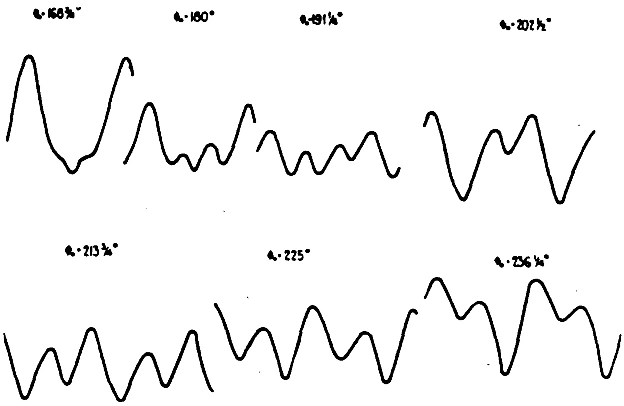


FIGURE 47—Synthetic Wave Forms Showing Distortion Due to Frequency Modulation

relation as shown on the lower right of Figure 46, we have the envelope of the resultant wave at the receiver.

When the mean position of the two vectors (a) and (b) in Figure 27 is 180 degrees separation, the signal is experiencing a fading minimum. When they are on the average in phase the amplitude is at a maximum. We can, therefore, trace a relation between quality distortion and fading by such an analysis, assuming a constant percentage modulation. Figure 47 shows a series of high-frequency wave envelopes obtained by this method of graphic analysis. The mean vector relation is represented by ϕ_0, and for $\phi_0 = 180$ degrees the fading may be considered at a minimum. The waves shown in Figure 47 being envelopes of the high frequency, will undergo certain changes in the process of detection. These, however, would only slightly modify the wave.

For purposes of comparison, a set of oscillograph pictures of

representative received wave shapes is shown in Figure 48. These represent the actual effect of night-time transmission with frequency modulation between 463 West Street, New York City and Stamford, Conn.; the modulating tone was a practically pure 264-cycle sinusoidal wave. The samples have been arranged in successive order to correspond with the order shown in Figure 47. There exists a striking similarity. Occasionally, however,

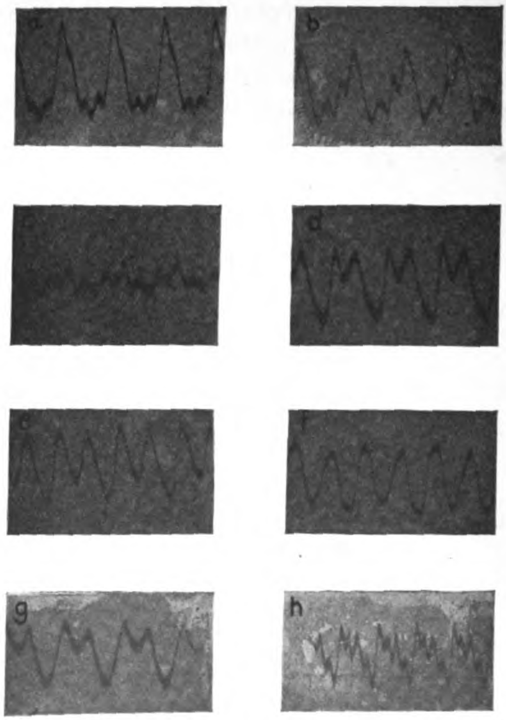


FIGURE 48—Oscillograms Showing Actual Wave Forms with Distortion Resulting from Frequency Modulation

the shapes predicted may depart considerably from those obtained experimentally. As an example of such a departure, the record (h) in Figure 48 has been included. Such unusual samples may be due to a combination of waves arriving over more than two paths or it may be that the time variation of the frequency is far from the simple sinusoid which we have assumed. As a matter of fact, a critical mathematical treatment of this case shows that only an approximation of such a sinusoidal condition is

possible since, as has been shown by Carson,[4] a frequency modulated wave of this character consists of an infinite series of fixed frequencies spaced at regular intervals either side of a "fundamental" carrier wave. Obviously, only a small part of such a series could get out of the transmitter or into the receiver due to circuit selectivity. For the lower modulating frequencies, however, the approximation involved in the assumption of a simple sinusoidal variation is not far wrong since the amplitudes of these side frequency components fall off rapidly as their order in the series increases. While 150 wave lengths difference in path length has been assumed for the synthesis of the wave shapes in Figure 47, this difference may, according to the data obtained, amount to much more than this.

It may well be asked why this frequency modulation, since it produces such marked distortion at night in certain places, does not also give rise to distortion by day or in locations where transmission is steady. A full answer to this question would be far from simple. But in brief it is because the carrier and side bands shift in absolute frequency together as a unit so that their relative or difference frequencies which determine the audio signal remain unchanged. Another way to put it is that the detector operates on the envelope of the high-frequency signals and is blind to the frequencies contained within the envelope except insofar as they affect the latter. However, since frequency modulation appreciably widens the frequency band occupied by the radio signals, it is to be expected that the tuned circuits in the receiver would have some reaction on those louder portions of the signal for which the amplitude modulation and, therefore, the frequency modulation, is large. The perfection with which broadcast signals may be received under suitable conditions leads one to believe that this effect must be small.

Fading in Relation to Form of Transmission

It has been shown that serious wave form distortion of the reproduced signal may result if frequency modulation occurs with the amplitude modulation and the transmission is subjected to night-time conditions. This distortion from frequency modulation can be eliminated by stabilizing the carrier frequency. There remain some wave form distortion and the annoying amplitude changes caused by selective fading which is one of the most serious present day problems in radio transmission. Let us now

[4] See "Notes on the Theory of Modulation," by John R. Carson, February, 1922. Proceedings of The Institute of Radio Engineers.

consider the nature and cause of this residual wave form distortion and some further consequences of selective fading under the assumption that there is no frequency modulation involved.

The process of detecting audio signals from radio frequency signals is, at least in its simpler aspects, well understood, but it may not be generally appreciated that the action is such that the detected signals may be greatly modified by changes in the relative amplitudes and phases of the carrier and side-band components such as may result from their transmission through the medium. That the amplitudes and phases of the carrier and side-band signals are not necessarily received in the same relation that existed as they left the transmitter, has been pointed out earlier, in the discussion on selective fading.

The usual expression for a high-frequency carrier wave of frequency $p/2\pi$ modulated by a low-frequency wave of frequency $v/2\pi$ is

$$e = A[1 + a \sin (vt + \phi)] \sin pt$$

where A is the carrier amplitude, a, the percentage modulation and ϕ the starting phase of the modulating tone with reference to the carrier. Expanded into its components this becomes

$$e = \frac{A_1 a}{2} \cos (pt + vt + \phi_1) \qquad \text{(the upper side band)}$$

$$- \frac{A_2 a}{2} \cos (pt - vt - \phi_2) \qquad \text{(the lower side band)}$$

$$+ A_3 \sin pt \qquad \text{(the carrier)}$$

where $\phi_1 = \phi_2 = \phi$ and $A_1 = A_2 = A_3 = A$ as the waves leave the transmitting antenna.

In the receiving set this function is squared by the action of the detector and, neglecting direct currents and frequencies above the audio range, the result is

$$\frac{a}{2} A_3 [A_1 \sin (vt + \phi_1) + A_2 \sin (v + \phi_2)] +$$

$$A_1 A_2 \frac{a^2}{4} \cos (2vt + \phi_1 + \phi_2) \qquad (17)$$

of which the first term represents the fundamental frequency of the original modulating tone and the second term the second harmonic.

From this expression several conclusions can be immediately drawn. Due to the action of the detector there is always some slight wave form distortion, as is evidenced by the presence in relatively small amplitude of the second harmonic. In the

ordinary case this is negligible. The first term contains the carrier amplitude as a factor, but the second term does not. Thus, if selective fading erases the carrier at any time, reducing its amplitude to zero or a small value, the signal, represented by the fundamental tone, practically disappears, *even though the side bands have not faded out*, and there remains only the harmonic. This is the residual distortion shown in Figure 41 and which can often be heard during a fading-out period. It is caused by the two side bands beating together in the detector. We have here exposed a fundamental defect in the usual form of modulated signal transmission. The amplitude of the received signal is subject to all the whims of the carrier and, to paraphrase freely an old saying, we might remark that a signal is no stronger than its carrier. We may at once conclude that one way to reduce fading is to suppress the carrier and resupply a constant amplitude carrier at the receiving station.

Analyzing further the first term of the expression representing the detected signal, the first part of the bracketed portion results from beating together in the detector of the carrier and upper side band and the second part from the carrier and lower side band. It is clear that one of the side bands may fade out completely and the other will still bring in the signal, provided the carrier is not also lost, with a phase shift to be sure but nevertheless not seriously reduced in amplitude. In telephony this kind of phase shift is relatively unimportant. Here we have an evident advantage in transmitting both side bands since they support each other's frailties. But if the two side bands suffer phase shifts in transmission, as we have earlier shown may be produced by wave interference, such that Φ_1 and Φ_2 differ by π radians or 180 degrees, the two components will cancel each other provided their amplitudes A_1 and A_2 remain equal. In other words, all three components—carrier and both side bands—may arrive at the receiver with full amplitude and yet no signal will be detected from them except a second harmonic component. This is obviously a disadvantage of transmitting both side bands since, at such an instant, if one of them were eliminated, the signal would reappear.

We conclude that there is, on the basis of such a brief analysis, not much to choose between single side-band and double side-band transmission when the carrier is transmitted also.

But if we wish to realize the advantages of carrier suppression, a choice is not difficult. A carrier suppression system in which both side bands are transmitted requires that the replacement

of the carrier at the receiving station be done with almost absolute accuracy as to frequency and phase, a thing which involves very serious practical problems. On the other hand, if but a single side band is transmitted, the difficulty is reduced to placing the carrier within a very few cycles of its correct position. The allowable departure will depend on a number of things, but there is reason to believe that for high quality transmission it must be very small, perhaps no greater than two or three cycles.

With the single side-band carrier suppression method, invented by John R. Carson, the radiation is stripped down to the minumum, which will fully transmit the telephonic signals, and this reduces to a minimum the exposure of the signals to the ravages of selective fading. If the spacing interval of the fading is relatively narrow, as in the cases we have examined hereinbefore, this form of transmission would not fade seriously in average volume, but would be subjected to a continual changing of its frequency-amplitude characteristic, that is to say, individual frequency components would fade progressively as the minima of the selective fading wandered back and forth across the frequency range encompassed by the single side band. If the spacing interval of the fading were very large so that the minima were very broad or if some other at present unexplored form of fading which covers a wide band at one time were acting, the signal would fade in average volume, but the range of its variation would be only the square root of that of a carrier transmitted signal, since only the side band would fade and the locally supplied carrier would remain unchanged.

The extent to which these theoretically drawn conclusions may be realized in practical application is yet to be determined, but we have a few records bearing upon the matter which at least do not run contrary to them.

All of the transmission tests where the radio signal was beat with a local oscillator and the detected beat note observed, were equivalent to single frequency single side-band transmission with carrier suppression, the local oscillator functioning as the carrier suppressed at the transmitter. In this case, for which a number of records have already been shown, the detected signal is in proportion to the product of the amplitudes of beating oscillator and received radio signal. The phase of either does not affect the amplitude of the audio signal. Hence the only important modification of the original signal is the variation in the amplitude resulting from selective fading.

Unfortunately, we have no records in which a direct com-

parison is made between single side-band transmission with and without carrier suppression, but the case can be visualized from the record shown in Figure 12 or 13. Here each one of the frequencies recorded may be looked upon as a single side-band frequency which has been detected through the agency of the resupplied carrier of the beating oscillator used to bring them down to audio frequency. If now we were to take two of these frequencies shown on the record and multiply their amplitudes together at each point, we would obtain the amplitude of the signal which would result if one of them were a single side band and the other its accompanying carrier. It is obvious that the fading variations would thereby be increased in amplitude and rapidity.

In order to obtain a comprehensive picture of the relative advantages of radio transmission using a carrier and one side band as compared with the common practice of transmitting both side bands, the following tests were made. The schematic diagram of the circuit arrangement is shown in Figure 49. At the

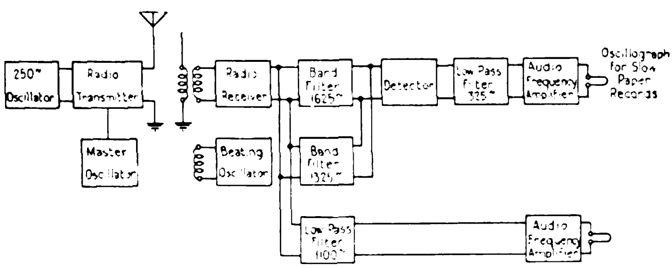


FIGURE 49—Diagram of System Used to Obtain Records of Transmission with Carrier and One Side Band and Carrier and Both Side-Bands

transmitter the carrier and both side bands are transmitted, and at the receiver they were selected out by means of filters in the manner previously explained. The signals from the filters corresponding to the carrier and lower side band were applied to the input of a detector circuit and from its output the detected difference signal was selected by a low-pass filter. This signal was equivalent to that which would be received if only the carrier and one side band were transmitted. From the output of the radio receiver a branch circuit goes to a low-pass filter which transmits only the signal detected from the carrier and both side bands, suppressing from this circuit the higher frequency signals corresponding to carrier and side bands produced by the beating oscillator and received signals.

By making simultaneously a record of these two signals a direct comparison is obtained of the effect of selective fading on their amplitudes. Figure 50 shows samples of several such records made at Riverhead, L. I. The modulating frequency for strips 1, 2 and 3 is 250 cycles, and for strips 4 and 5, 500 cycles. The record on strip 3 is shown on account of the peculiar characteristic of the signal fading, for considerable periods of time remaining at relatively low amplitude. In these oscillograms the upper trace is the record of the signal from the carrier and both side bands, and the lower trace the signal from the carrier and lower side band.

These records illustrate by giving a graphic comparison the effect of the phase changes of the component signals in the case where the signal is detected from both side bands. The amplitude of the signal from both side bands in some instances is very small, but appreciable amplitude is still indicated at the same instant for the signal from one side band. This is explained as meaning that the side-band phases were such as to make the component signals 180 degrees out of phase after detection and that the amplitudes of the components were practically equal. The reverse situation is also observed where the amplitude of the signal detected from the lower side band is zero and appreciable signal is recorded for the case where both side bands are used. This is interpreted to mean that the side-band signal was eliminated by selective fading. In this event it was, of course, not contributing to the signal which was detected from both side-band signals. The recorded signal comes from the other side band which evidently was not eliminated at that instant by selective fading.

Visual observations made with the cathode ray oscillograph, which unfortunately furnishes no permanent record of transient effects, confirmed the strip records in regard to the reality of there being side-band phase variations. From equation (17), it is seen that if these variations occur, the fundamental of the detected tone signal at the receiver will not bear a fixed phase relation to that detected from the transmitting antenna current, while if there are no such changes the phase between these two tones would remain constant. The locally detected tone and the tone detected from the transmitting antenna current and brought to the receiving station over telephone wires, were applied to the two pairs of deflecting plates in the cathode ray oscillograph. Since the deflections caused by these two pairs of plates are at right angles to each other, the resulting Lissajous figure from two

sine waves of the same frequency will be a slanting line, an ellipse or a circle depending on their phase and amplitude relation. The actual figures were observed to change progressively through this range of shapes, the changes following roughly the magnitude

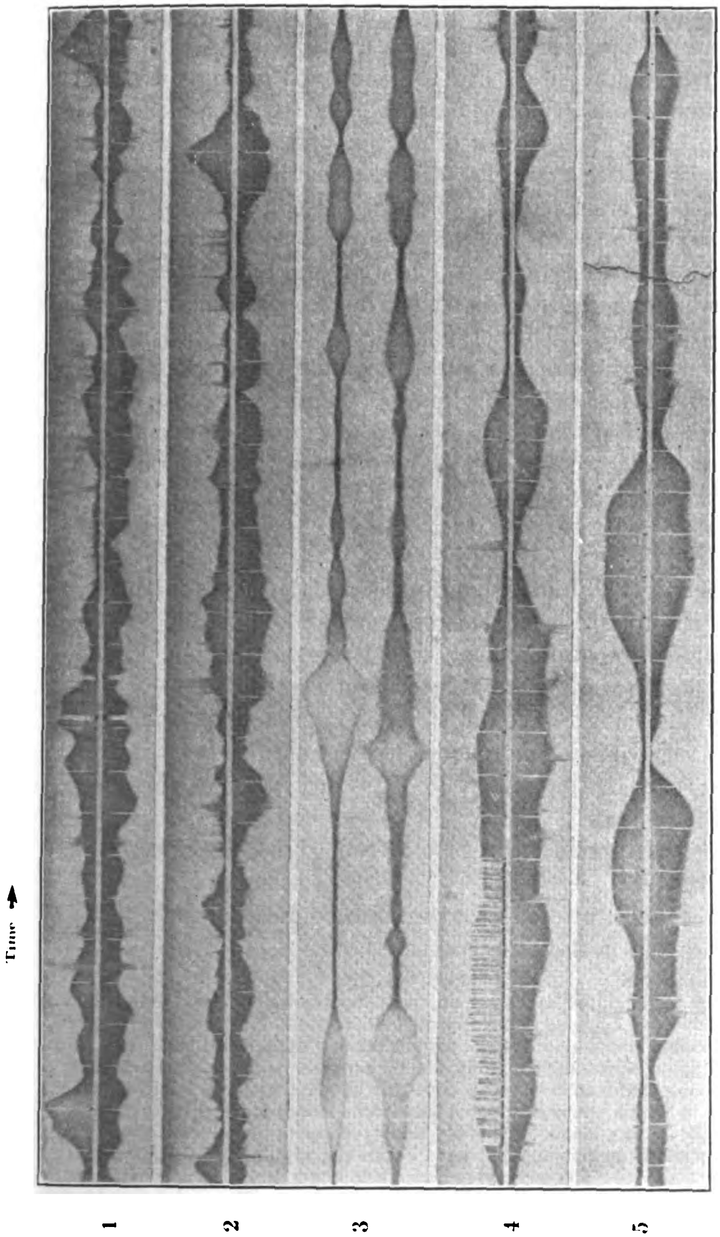


FIGURE 50—Slow Record Comparing the Signal Detected from Carrier and One Side Band with Signal Detected from Carrier and Both Side Bands. Made at Riverhead, L. I. Upper trace carrier+both side bands, lower trace carrier+one side band. Strips 1 and 2, July 22, 1925, 1.46 A. M. 250-cycle modulating tone. Strip 3, July 21, 1925, 3.10 A.M. 250-cycle modulating tone. Strips 4 and 5, July 23, 1925, 2.47 A. M., 500-cycle modulating tone.

and rapidity of the fading. The effect of amplitude changes on such figures is quite distinct from the effect of phase changes, and there was no difficulty in separating out the evidence of large phase changes.

Considering only the above theories and facts, there appears to be a reasonable basis for a conclusion that the best form of radio transmission for use in broadcasting is single side band with carrier suppression. But on practical grounds we do not believe such a conclusion is justified. The fading and distortions which we have made much of in the preceding pages are not experienced by the majority of broadcast listeners when they listen to local stations. To require these listeners to provide themselves with more complicated and expensive receivers, simply to allow more distant or less favorably situated listeners to obtain better reception, seems neither reasonable nor desirable. The art offers several other possible avenues toward improvement much less difficult of application and it must be remembered that radio broadcasting is already reaching a degree of standardization and a volume of existing receiving equipment which rules that changes must come slowly and without serious prejudice to the existing order.

Conclusions

Subject to the limitations imposed by the scope of our investigations the following conclusions may be drawn:

Fading can be quite sharply selective as to frequency and the evidence points toward wave interference as the cause.

The evidence for wave interference indicates that some of the energy of received signals reaches its destinations by a circuitous route and suggests that this route is by way of upper atmospheric regions.

Quality distortion may result from dynamic instability of the transmitter.

Fixed wave interference patterns in connection with shadows sometimes exist in daytime transmission.

SYNOPSIS: The paper is based on radio transmission tests from station 2XB in New York City to two outlying field stations. It is a detailed study of fading and distortion of radio signals under night-time conditions in a particular region which may or may not be typical.

Night-time fading tests using constant single frequencies and bands of frequencies in which the receiving observations were recorded by oscillograph show that the fading is selective. By selective fading it is meant that different frequencies do not fade together. From the regularity of the frequency relation between the frequencies which fade together it is concluded that the selective fading is caused by wave interference. The signals appear to reach the receiving point by at least two paths of different lengths. The

paths change slowly with reference to each other, so that at different times the component waves add or neutralize, going through these conditions progressively. The two major paths by which the interfering waves travel are calculated to have a difference in length of the order of 135 kilometers for the conditions of the tests. Since this difference is greater than the distance directly from transmitter to receiver, it is assumed that one path at least must follow a circuitous route, probably reaching upward through higher atmospheric regions. Various theories to explain this are briefly reviewed.

The territory about one of the receiving test stations in Connecticut is found under daytime conditions to be the seat of a gigantic fixed wave interference or diffraction pattern caused in part by the shadowing of a group of high buildings in New York City. The influence of this pattern on night-time fading is discussed. It is considered a contributing but not the controlling effect.

Tests using transmission from an ordinary type of broadcasting transmitter show that such transmitters have a dynamic frequency instability or frequency modulation combined with the amplitude modulation. At night the wave interference effects which produce selective fading, result in distortion of the signals when frequency modulation is present. It is shown that stabilizing the transmitter frequency eliminates this distortion. A theory explaining the action is given. The distortions predicted by the theory check with the actual distortions observed.

A discussion of ordinary modulated carrier transmission, carrier suppression, and single side band transmission is given in relation to selective fading. It is shown that the use of a carrier suppression system should reduce fading.

THE PRESENT STATUS OF RADIO ATMOSPHERIC DISTURBANCES*

By

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(Laboratory for Special Radio Transmission Research)

(Conducted jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy)

Our knowledge concerning the atmospheric disturbances is still very meager. The observed facts may be cataloged as follows: (1) In general, atmospherics are stronger at the longer wave lengths. (2) Except for the effects of local storms, they are nearly always stronger in the afternoon and night, while for the higher frequencies this increase in strength is confined usually to the night alone. (3) They are stronger in summer than in winter, (4) in the south than in the north, and (5) on the land than on the ocean. (6) A large proportion of them appear to be directive; that is, to come from definite regions, or centers, as mountain ranges, rain areas, or thunderstorms. It is also reasonably certain that (7) at least most of the long-wave disturbances travel along the earth with a practically vertical wave front,[1] like the signals; (8) that a considerable portion are oscillatory in character, though a certain portion are non-oscillatory and give rise to shock oscillations in the antenna at all wave lengths; and (9) that disturbances sometimes occur simultaneously at stations thousands of miles apart.[2]

The origin of the ordinary rumbling disturbances (grinders) has been the subject of many conjectures. Eccles[3] believed at one time that he had found the source of this type of disturbance, as far as England was concerned, in distant thunderstorms, espe-

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[1] Jnl. Wash. Acad. Sci., volume 11, page 101, 1921.

[2] M. Baumler, Jahrb. d. Drahtlosen Teleg., volume 19, page 325; 1922. This matter of simultaneous crashes needs further investigation since a certain number of such coincidences may evidently occur by chance.

[3] Electrician (London), volume 69, page 75; 1912.

cially in Western Africa. DeGroot[4] has suggested that the grinders are due to the bombardment of the upper atmosphere by electrons from the sun or charged cosmic dust. The idea that this type of disturbance comes in some way from above has also been held by Weagant.[5] Mosler,[6] while ascribing the disturbances to thunderstorms, concluded in contradiction to the ideas of Eccles, that thunderstorms could give rise to atmospherics only over a radius of about 60 miles. This limitation in distance was very probably due to insensitive apparatus. A very systematic study of thunderstorms and atmospherics, undertaken by the British Meteorological Office and the Admiralty, has apparently settled the fact that thunderstorms can be located with modern apparatus up to about 1,500 miles.[7]

There is still much difference of opinion as to the proportion of atmospherics which is due to thunderstorms. Professor Appleton, at a symposium[8] on atmospheric ionization and radiotelegraphy, November 28, 1924, expressed the opinion that practically all atmospheric disturbances might be produced by thunderstorms somewhere in the world.

It is undoubtedly true that thunderstorms produce many atmospherics, but it is not by any means certain that the lightning flashes themselves are always the actual sources. There is a widely prevailing idea among radio operators that the lightning flash often produces only a harmless click in the telephone receivers. I have made some observations during thunderstorms, using a coupled circuit with rectifying vacuum tube and galvanometer, which indicated that lightning flashes, even within three or four miles, were not as powerful in their effects on the receiving apparatus as many of the disturbances which occurred when no flashes were apparent. This comparatively feeble effect of the flashes is difficult to understand if the current rise at the beginning of the flash is as steep as is often assumed, but would be understandable if the lightning discharge curves were of the form and duration of the atmospheric disturbance curves observed by Appleton and Watt (Figures 1 to 5). On the other hand, it is quite possible that the small deflections from the lightning flashes were due to a paralysis of the detector tube, a phenomenon which often occurs when the tube is exposed to very high electro-

[4] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, page 75; 1917.

[5] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 7, page 207; 1919.

[6] Elektrot. Zeits., page 1134; 1912.

[7] World Power, volume 3, page 20; 1925.

[8] Proc. Phys. Soc., London, volume 37, Page 2D-50D (appendix), 1925.

motive forces. It must, therefore, be concluded that the connection between lightning and atmospherics is still not clear, and valuable work can be done by anyone who will watch the lightning and listen to the atmospheric crashes from thunderstorms in the neighborhood.

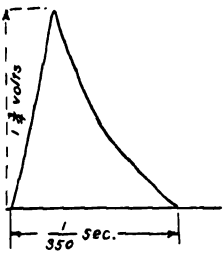

FIGURE 1

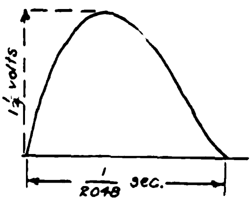

FIGURE 2

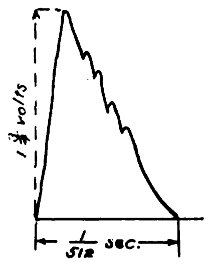

FIGURE 3

At the London Physical Society symposium already mentioned, Professor C. T. R. Wilson discussed the probability of there being discharges of thunderclouds to the upper conducting region of the atmosphere. His calculations indicated that thunderclouds of common electric moment might very readily discharge to a conducting layer at a height of 60 or 80 kilometers, since the electric force required to produce discharge decreases even more rapidly with the height than the electric force of the thundercloud. Discharges of this kind, probably non-luminous, may possibly furnish the explanation of the strong atmospherics heard from thunderclouds when no flashes are visible.

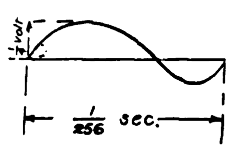

FIGURE 4

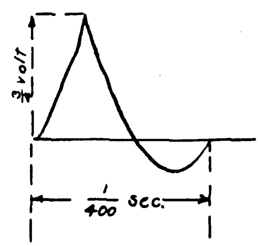

FIGURE 5

Mr. Watson Watt, in analyzing the records of European[9] direction-finding stations, concluded that in only about 35 percent of the cases could thunderstorms be identified as the sources of atmospheric disturbances, though in about 75 percent of the cases the identified sources were rain areas of some kind.

[9] Nature, 110, page 680, 1922.

Captain Bureau[10] of the French Meteorological Office has recently published papers in which he shows that many of the atmospheric disturbances in France are closely connected with the advance of meteorological cold fronts and that the atmospherics are accentuated when these air movements come in contact with mounted ranges.

For the determination of the direction from which atmospheric disturbances come, Mr. Watt[11] has invented an automatic recording apparatus in which a radio compass coil, tuned to about 30,000 meters, is rotated slowly and continuously by clockwork, the atmospheric crashes being recorded on a drum attached to the coil.

It should be said in this connection that it has been very common in Europe to estimate the strength of atmospherics by the number of disturbances occurring in a given time. This method, of course, would hardly seem to be applicable to our Washington summer conditions, or to the conditions during the disturbance season in the tropics, where often in the afternoons and evenings the noise in the telephones forms an almost continuous rumbling through which no signal can be heard unless it is strong enough to rise above the background of disturbing sounds.

If, indeed, there is a physical difference between the atmospherics, crashes, grinders, etc., it is not at all certain that what is being measured in Europe by the counting method is the same thing that is being measured in America, either by direct estimates of the average disturbance strength, or by measuring the strength of signal which can be read through the disturbances.

On the Atlantic and Pacific coasts of the United States, except for occasional local thunderstorms, very little certain connection has been noticed between the direction of the atmospheric disturbances and rain areas. On the Atlantic coast, the main disturbances seem to come roughly from the southwest, but it seems uncertain whether the sources are in the Allegheny Mountains or much farther removed, perhaps in Yucatan. Experiments reported by the Navy Department in New Orleans have indicated the more southerly origin.

Unfortunately, very few triangulation experiments have been made in America for fixing the exact positions of sources of atmospherics. In most cases, therefore, the direction is all that is known.

[10] C.-R. Acad. Sci., volume 176, page 556 and page 1623, 1924; L'Onde Electrique, volume 3, page 385, 1924.

[11] Proc. Roy. Soc., A, volume 102, page 460, 1923; and Phil. Mag., volume 45, page 1010, 1923.

Observations made at Madison, Wisconsin, by Professor Terry of the University of Wisconsin, covering the last two years, show conditions in the Middle West which are similar to those described by the continental European observers; that is, there is no single prevailing direction of the atmospherics, but a more or less definite connection with thunderstorms and other rain areas. This absence of any prevailing southerly source of atmospherics in the central portion of the country casts doubt on the Mexican origin of those observed in the Atlantic Coast region, since the distance from Yucatan to Madison, Wisconsin, is about the same as from Yucatan to Washington.

On the Pacific Coast of the United States it is pretty well established that at least at San Francisco and San Diego the sources of disturbance are largely local, lying in the mountain ranges not far from the coast. These centers seem to be permanently fixed, resulting in very constant directional conditions.

It seems to be pretty well settled, in all parts of the world where observations have been made, that there is a very definite connection between the intensity of the disturbances and the position of the sun. In the northern hemisphere during the winter when the sun is far in the south, the disturbances are generally moderate even as far south as Panama, within 9 degrees of the equator. But as the sun comes north in the spring, there is often a rapid and, sometimes, very sudden increase in strength, and it is reported that stations close to the equator experience two disturbance maxima, corresponding to the two periods when the sun is nearly overhead.

In addition to the study of the sources of the disturbances, the question of their wave form is of much importance. Messrs. Watt and Appleton[12] in England, working under the Radio Research Board, have made some investigations of this problem, making use of the cathode-ray oscillograph (Braun tube). In their work the atmospheric disturbance, after being received on an aperiodic antenna and amplified by an aperiodic resistance-coupled amplifier, was impressed on one pair of plates of the oscillograph, while a source of 60-cycle current was connected to the other pair of plates for the purpose of drawing out the spot of light into a line on the fluorescent screen. The resulting movement of the spot of light could not be photographed, but could be observed and sketched with some accuracy. Five typical curves are shown in the figures. Most of these appear to be aperiodic though some are feebly oscillatory.

[12] Proc. Roy. Soc., A, volume 103, page 84, 1923.

In Figure 3 it is seen that there are minute oscillations superposed on the main curve. It will be noted that the period of the main oscillation is, in all cases, of audio frequency; and Ecklersley[13] has pointed out recently that the relatively prolonged impulses of Watt and Appleton cannot account for the observed intensity of the atmospherics ordinarily experienced in radio reception. He suggests that possibly the ripples, such as are shown in Figure 3, may be the actual atmospheric waves. Mr. Watt in the symposium cited accepts this view and adds that more recent experiments in Egypt and elsewhere in the tropics show that there the fine ripple structure is much more common and of much greater amplitude than in England. Professor Appleton, on the other hand, holds that the low-frequency wave forms shown in the figures are capable of producing the observed disturbances at all wave lengths by shock excitation.

In conclusion, the differences of opinion mentioned in this paper show that there is still much to be done before the sources of the disturbances are identified with certainty. While many of the atmospherics undoubtedly come from thunderstorms, many appear to come from regions where no such storms are occurring. It is also believed that even in thunderstorms some of the heaviest disturbances do not come from the lightning itself, but the nature of these non-luminous sources of such great power is still a matter of conjecture.

Bureau of Standards,
Department of Commerce,
Washington, D. C.

SUMMARY: The paper gives a résumé of our present knowledge concerning atmospheric disturbances. It is found that in Europe about thirty percent of these come from thunderstorms, while 75 percent are associated with rain areas of some kind. In the United States, near the Atlantic Coast, disturbances in general come from the southwest, while on the coast of California they come from permanent centers in the neighboring mountains. In the Middle West the direction is variable, depending on thunderstorms, rain areas, etc. In England, cathode-ray oscillograms have been taken of the atmospherics. The main disturbance is of audio frequency and usually aperiodic. Some of the curves show high-frequency ripples on the main waves. These may be the real sources of atmospheric troubles.

[13] Electrician (London), volume 93, page 150. 1924.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued November 3, 1925—December 29, 1925

By
JOHN B. BRADY

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,559,723—F. E. MANN, Cherrydale, Virginia. Filed December 10, 1923, issued November 3, 1925.
CRYSTAL DETECTOR, where a crystal holder is arranged to be mounted adjacent a panel and an adjustable arm mounted within the panel and controllable from the front thereof for properly setting the detector.

1,559,743—H. J. J. M. DeBELLESCIZE, Paris. France. Filed August 29, 1921, issued November 3, 1925.
RADIO RECEIVING SYSTEM for reception of continuous wave signals without a heterodyne in which a periodic antenna is provided with a tuned and detuned receiver associated therewith, the receiver being differentially coupled with an indicating device for securing response to the continuous wave signaling energy.

1,559,776—H. S. READ, New Haven, Connecticut. Filed December 9, 1919, issued November 3, 1925. Assigned to Western Electric Company.
THERMIONIC REPEATER OR OSCILLATOR CIRCUITS, in which an electron tube having a heated cathode and a controllable cathode heating circuit is provided with means for maintaining the energization of the cathode heating circuit at a predetermined value for a desired condition of oscillation of the circuit.

1,559,802—G. H. STEVENSON, Rye, New York. Filed May 16, 1921, issued November 3, 1925. Assigned to Western Electric Company.
ELECTRICAL SWITCHING CIRCUITS, whereby inductance and capacity changes in a circuit may be conducted simultaneously.

1,559,869—R. V. L. HARTLEY, East Orange, New Jersey. Filed September 23, 1919, issued November 3, 1925. Assigned to Western Electric Company.
SELECTIVE CURRENT PRODUCTION AND AMPLIFICATION by means of electron tubes in which a harmonic producer having an output circuit and a control circuit is provided with a plurality of selective paths in said output circuit and an individual coupling between each of the selective paths and the control circuit. Harmonics of different frequencies are developed from a given space frequency.

1,559,974—G. J. MULLIGAN, Columbus, Ohio. Filed March 8, 1924, issued November 3, 1925.
VARIABLE ELECTRIC CONDENSER, in which a tank containing mercury has its mercury content displaced by the lowering of an adjustable member therein for varying the capacity with respect to an outer plate.

1,559,992—W. SCHAFFER, Berlin, Germany. Filed August 18, 1922, issued November 3, 1925. Assigned to Gesellschaft fur Drahtlose Telegraphie.
ARRANGEMENT FOR FREQUENCY TRANSFORMATION PARTICULARLY FOR OPERATING RELAY STATIONS, in which an electron tube circuit is operated at a receiver by incoming signaling energy and the output circuit of the tube system arranged to control the grid

*Received by the Editor, January 16, 1925.

potential of the transmission system for reradiating the received signaling energy.

1,560,056—J. W. HORTON, Bloomfield, New Jersey. Filed May 1, 1923, issued November 3, 1925. Assigned to Western Electric Company.
SOURCE OF WAVES OF CONSTANT FREQUENCY, in which a tuning fork having a fundamental frequency equal to the frequency of the generator is arranged for controlling the operation of a synchronous motor so as to operate in synchronism with the generator for performing various purposes where constant frequency is required.

1,560,206—E. L. CHAFFEE, Belmont, Massachusetts. Filed April 25, 1918, issued November 3, 1925. Assigned to John Hays Hammond, Jr.
METHOD AND SYSTEM FOR THE TRANSMISSION OF RADIANT ENERGY and the reception of signaling energy where the detector is protected against excess static effects by means of parallel arranged tubes in circuit therewith.

1,560,310—C. PFANSTIEHL and W. O. BELL. Highland Park, Illinois. Filed January 2, 1924, issued November 3, 1925. Assigned to Pfanstiehl Radio Company.
GRID LEAK CONDENSER, in which alternate dielectric and conductive plates are provided with apertures in the dielectric plates through which a grid leak passes in parallel with the conductive plates.

1,560,390—J. G. LIEBEL and E. S. FLARSHEIM, of Cincinnati, Ohio. Filed September 24, 1923, issued November 3, 1925
SPARK GAP for high frequency discharge circuits in which a plurality of spark gaps are adjustably arranged in a frame with means for preventing excess heating of the gaps.

1,560,431—A. SCHMIDT, JR., Schenectady, New York. Filed July 3, 1923, issued November 3, 1925. Assigned to General Electric Company.
SIGNALING SYSTEM, in which an electron tube oscillator is modulated by means of an auxiliary tube system which is varied in resistance in accordance with a simultaneous change in negative potential upon the grid of the oscillator tube for the production of signals.

1,560,690—W. G. HOUSEKEEPER, New York. Filed April 21, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the plate is formed in the shape of a depending metallic cup sealed to the glass container and enclosing the other electrodes within the tube.

1,560,691—W. G. HOUSEKEEPER, New York. Filed May 28, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the filament is maintained taut by means of a spring carried by an insulated member which extends across the top of all of the electrodes.

1,560,692—W. G. HOUSEKEEPER, New York. Filed June 13, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the anode is formed by a pair of plates joined at their outer edges and locked together to form a substantially continuous plate member.

1,560,737—P. SCHWERIN, New York. Filed May 22, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, where an insulated block is provided across the top of the tube electrodes with a tubular member passing therethrough and supporting a spring device by which the cathode is maintained under tension.

1,560,740—J. L. STELLING, New York. Filed July 22, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the electrodes are supported by means of a collar which embraces the re-entrant stem of the tube where the stem is sand blasted or roughened to insure a good support for the tube electrodes.

1,560,761—L. COHEN, Washington, D. C. Filed June 5, 1922, issued November 10, 1925.
VARIABLE CONDENSER, where the stationary and variable plates of the condenser are varied in special relationship by axial movement of a central shaft.

1,560,854—J. H. PRESSLEY, Oceanport, New Jersey. Filed October 16, 1924, issued November 10, 1925.
RADIO RECEIVING APPARATUS, in which the circuits of an electron tube oscillator are balanced by a mesh circuit or wheatstone bridge so that the tuning of the receiving circuit does not affect the tuning of the local oscillator circuit in a continuous wave receiver.

1,560,911—C. F. M. HAYES and L. GRINSTEAD, London, England. Filed February 10, 1923, issued November 10, 1925. Assigned to Mullard Radio Valve Company, Limited.
VACUUM TUBES where the electrodes are mounted from a band which encircles the stem within the tube, the band being wedged against the stem to insure rigid support for electrodes.

1,561,001—I. LANGMUIR, Schenectedy, New York. Filed February 7, 1921, issued November 10, 1925. Assigned to General Electric Company.
ELECTRIC OSCILLATOR of the two-electrode variety in which a cathode and anode are sealed within a vessel filled with an inert gas at a pressure of the order of 0.005 to 0.075 millimeter of mercury.

1,561,228—J. H. HAMMOND, JR., Gloucester, Massachusetts. Filed February 16, 1921, issued November 10, 1925.
CAPACITY COMPENSATING DEVICE for an antenna system which is subject to change in position. A condenser is provided with automatic means for varying its capacity in proportion to the variation in capacity of the antenna circuit, due to the movement of the antenna with respect to the earth.

1,561,258—S. LOEWE, Berlin, Germany. Filed July 27, 1921, issued Novvember 10, 1925.
PROCESS FOR TESTING SPARK STATIONS, which consists in connecting a direct-current instrument to a part of the system undergoing periodical electrical changes and observing whether the direct-current instrument gives a constant reading

1,561,273—H. W. NICHOLS, Maplewood, New Jersey. Filed November 24, 1924, issued November 10, 1925. Assigned to Western Electric Company.
RADIO SYSTEM for high power speech transmission, where energy is supplied to rectifying devices at several thousand volts and the energy of the amount of 100-kilowatts or more supplied to the transmission circuit. The high power amplifier of the transmission system is supplied with direct-current potential from a two-phase alternating-current source and a rectifier in which the ripple component resulting from rectification is supplied to the space path of the amplifying tube at the same time that the filament electrodes of the amplifying tubes are supplied directly from alternating current.

1,561,559—J. O. MAUBORGNE, LOUIS COHEN and GUY HILL, Washington, D. C. Filed April 8, 1921, issued November 17, 1925.
ELECTRICAL SIGNALING employing wave coils upon which are developed wave formations independent of undesired interference and the desired signaling energy selected by means of a receiving circuit coupled with the wave coils.

1,561,619—R. R. BEAL, Palo Alto, California. Filed January 5, 1920, issued November 17, 1925. Assigned to Federal Telegraph Company.
RADIO-TELEGRAPHY, in which an arc converter is employed with a signaling circuit for transmitting by means of a single wave, eliminating the compensating wave.

1,561,837—J. J. DOWLING, Rathgab, Dublin. Filed July 30, 1924, issued November 17, 1925.
THERMIONIC INDICATING MEANS RESPONSIVE TO LIGHT VARIATIONS, in which an electron tube amplifier is actuated by means

of variation in a source of light for actuating a relay which may be employed to operate any desired form of circuit.

1,561,914—H. F. ELLIOTT and J. A. MILLER, Palo Alto, California. Filed January 9, 1922, issued November 17, 1925. Assigned to Federal Telegraph Company.
RADIO FREQUENCY SYSTEM employing a plurality of arcs connected in branch circuits of an antenna system for supplying high frequency energy to the antenna system with impedance in series with each arc for preventing cross currents between the arc.

1,561,933—B. W. KENDALL, New York City. Filed August 7, 1918, issued November 17, 1925. Assigned to Western Electric Company.
SOURCE OF ALTERNATING CURRENT of constant frequency, where an electron tube is provided with an oscillation circuit and the anti-resonant circuit for determining the frequency of the oscillations generated. The anti-resonant circuit contains a magnetic core inductance with means for excluding uni-directional current from the inductance.

1,562,056—C. W. RICE, of Schenectady, New York. Filed April 21, 1921. issued November 17, 1925. Assigned to General Electric Company.
RADIO RECEIVING SYSTEM, in which a plurality of widely separated receiving antennas are connected by transmission lines to a central receiving station for avoiding interference from undesired signals and static.

1,562,172—W. G. HOUSEKEEPER, New York. Filed August 30, 1920, issued November 17, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, having a plate electrode formed of a tubular member, through which cooling water may be circulated.

1,562,209—B. J. EGERT and C. J. DE COSTER, of Brookfield and Moline, Illinois. Filed March 2, 1920, issued November 17, 1925. Assigned to Western Electric Company.
VACUUM TUBE EVACUATING OVEN, in which electron tubes are treated during the manufacturing process.

1,562,396—F. E. WARD, Corona, New York. Filed June 4, 1923, issued November 17, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the electrodes are supported by means of wire members provided with flat integral ears placed on opposite sides of a supporting plate member.

1,562,403—J. R. WILSON, New York. Filed December 19, 1924, issued November 17, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the cathode is supported by means of a helical spring and hook device for maintaining the cathode under tension with respect to the other electrodes.

1,562,485—H. A. AFFEL, Brooklyn, New York. Filed May 5, 1923, issued November 24, 1925. Assigned to American Telephone and Telegraph Company.
MOVEMENT AND POSITION INDICATOR, by which the speed of a moving station with reference to two fixed stations is determined. The method of determing this speed consists in simultaneously receiving waves of the same frequency radiated between the moving station and each of the fixed stations respectively, producing an indication proportionate to the relative phases of the received waves, which corresponds to the movement of the moving station, and determining from the number of cycles of relative phase shift per unit of time the number of wave lengths traveled by the moving station within that unit of time.

1,562,629—H. GERNSBACH, New York City. Filed September 27, 1923. issued November 24, 1925.
VARIABLE CONDENSER, in which a flexible metallic plate is adjusted with respect to a flat metallic plate, for varying the mutual capacity therebetween.

1,562,812—H. TRESS, Camp Alfred Vail, New Jersey. Filed March 26, 1924, issued November 24, 1925.
VARIABLE CONDENSER, in which the rotor and stator plates are aligned relative to each other by pin connectors extending into aligned sockets in each of the plates.

1,562,820—J. B. BRADY, Somerset, Maryland. Filed August 22, 1923, issued November 24, 1925. Assigned to Morkrum Company.
RADIO RECEIVING SYSTEM employing an automatic printer recorder by which signals are received and directly transcribed in print for transmission and reception of print by radio.

1,562,877—W. G. ELLIS, Philadelphia, Pennsylvania. Filed June 16, 1922, issued November 24, 1925.
RADIO RECEIVING SYSTEM, in which a loop receptor is employed with a circuit for improving the null or minimum point of reception in the receiving circuit for increasing the efficiency of the loop as a direction finder.

1,562,952—L. F. FULLER and G. C. SWEET, of Palo Alto, California and Waterloo, New York, respectively. Filed March 16, 1921, issued November, 24, 1925. Assigned to Wireless Improvement Company.
ARC CONVERTER, which is operated in polyphase, for the transmission of high-frequency signals.

1,562,961—R. A. HEISING, Milburn, New Jersey. Filed May 16, 1921, issued November 24, 1925. Assigned to Western Electric Company.
DIRECTIVE RADIO TRANSMISSION SYSTEM, where a long horizontal antenna is employed, which is progressively loaded for causing the antenna to radiate a uniform quantity of supplied energy per unit length of the antenna.

1,563,416—H. M. WOLFSON, New York City. Filed June 19, 1922, issued December 1, 1925.
VARIABLE CONDENSER, where the movable plates are helically formed and are advanced or retracted in an axial direction with respect to the rotor plates.

1,563,425—R. E. MARBURY, Edgewood Park, Pennsylvania. Filed June 17, 1920, issued December 1, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO RECEIVING SYSTEM, in which a local source of current of audible frequency is connected in circuit with a device so adjusted as to establish parallel resonance, one of the resonating elements embodying the audion bulb or amplifying device, the effect of the parallel resonance being to substantially prevent the flow of currents of audible frequency through the receiving device. Upon the occurrence of an incoming signal, the impedance of the amplifying device is modified and, consequently, the condition of parallel resonance is partially or wholly destroyed. As a consequence, currents of audible frequency traverse the receiving device, and clear and easily readable signals are produced therein.

1,563,440—A RUSSELL, Baltimore, Maryland. Filed February 3, 1925, issed December, 1, 1925. Assigned to Russell Radio Corporation.
VARIABLE CONDENSER, in which the plates are arranged in the form of concentric cylinders, which may be axially adjustable with respect to each other.

1,563,557—W. W. COBLENTZ, Washington, D. C. Filed September 18, 1923, issued December 1, 1925.
OPTICAL MEANS FOR RECTIFYING ALTERNATING CURRENTS, where a substance having inherent unidirectional selective conductivity when exposed to light is subjected to light rays for rectifying an alternating-current source.

1,563,620—W. S. GORTON, East Orange, New Jersey. Filed May 4, 1921, issued December 1, 1925. Assigned to Western Electric Company.
OSCILLATION GENERATOR, having means for predetermining the amplitude of the oscillating current produced by the generator, and also automatically operative to substantially compensate variations in the amplitude of said current.

1,563,644—H. W. NICHOLS, Maplewood, New Jersey. Filed December 13, 1924, issued December 1, 1925. Assigned to Western Electric Company.
WAVE RECEIVING SYSTEM, in which both the sum and difference components of the incoming signal wave and a locally generated oscillation, i. e., the sum and difference components resulting from intermediate

frequency detection are selected, separately detected, and combined in a receiver.

1,563,709—P. G. JACOBSON, Chicago, Illinois. Filed January 19, 1925, issued December 1, 1925.
ELECTROSTATIC CONDENSER construction where the rotor and stator plates are secured by clamping finger supports which extend between notched-out edges of the rotor or stator plates.

1,563,754—M. LATOUR, Paris, France. Filed August 19, 1921, issued December 1, 1925. Assigned to Latour Corporation.
ELECTRICAL CONDENSER of the fixed type where the conductive plate is bent into a U shape on opposite sides of an intermediate plate separated, therefrom by dielectric.

1,563,758—J. F. LINDBERG, Chicago, Illinois. Filed July 5, 1922, issued December 1, 1925. Assigned to Reliance Die and Stamping Company
CONDENSER of the variable type, where micrometer adjustment of capacity may be obtained by shifting the rotor by means of an auxiliary cam after an initial setting thereof.

1,563,893—S. COHEN, Brooklyn, New York. Filed March 14, 1925, issued December 1, 1925. Assigned to General Instrument Corporation.
MULTIPLE VARIABLE CONDENSER, in which a plurality of condenser elements are mounted on the same shaft and carried in the same condenser frame for simultaneous tuning of several electrical cirucits.

1,563,958—J. B. BRADY, Somerset, Maryland. Filed December 28, 1921, issed December 1, 1925. Assigned to Morkrum Company.
RADIO RECEIVING SYSTEM, in which automatic printers are used for setting down received signal impulses directly in print at a radio receiving station.

1,564,070—H. K. HUPPERT, San Francisco, California. Filed January 19, 1923, issued December 1, 1925.
RADIO VACUUM TUBE, in which the electron flow is varied by means of a magnetic field.

1,564,209—I.B. CRANDALL, Wyoming, New Jersey. Filed June 9, 1921, issued December 8, 1925. Assigned to Western Electric Company.
ELECTRICAL CIRCUITS FOR THE PRODUCTION OF MUSICAL TONES, for testing sensitiveness of the ear to sound.

1,564,627—H. J. ROUND, London, England. Filed March 31, 1920, issued December 8, 1925. Assigned to Radio Corporation of America.
RADIO TELEGRAPH AND TELEGRAPH TRANSMISSION, wherein a thermionic valve has a rapidly fluctuating voltage of square wave form applied to it and the energy developed in harmonics of the fundamental frequency is absorbed outside the device.

1,564,641—R. T. ST. JAMES, Chicago, Illinois. Filed April 10, 1922, issued December 8, 1925. Assigned to Chicago Miniature Lamp Works.
DETECTOR FOR RADIO SYSTEMS, in which a cylindrical plate electrode is supported by prongs which extend upwardly from the glass press within the electron tube.

1,564,672—C. J. HENSCHEL, Arlington, New Jersey. Filed June 15, 1922, issued December 8, 1925.
COMBINED SHIELD PLATE, DIAL AND VERNIER, where the rotatable dial is mounted upon a shield adjacent the apparatus panel and is adjusted at micrometer angular degrees for selectively setting the apparatus.

1,564,694—E. H. LERCHEN, East Orange, New Jersey. Filed October 10, 1922, issued December 8, 1925.
SHIELD FOR AMPLIFIER OR DETECTOR TUBES, where a metallic shield is fitted directly over an electron tube for preventing stray electromagnetic fields from affecting the operation of the tube.

1,564,807—E. F. W. ALEXANDERSON, Schenectady, New York. Filed May 4, 1918, issued December 8, 1925. Assigned to General Electric Company.
RADIO SIGNALING SYSTEM, in which an arc is modulated by means

of a control system associated with the antenna circuit, said control system comprising an inductance which is variable by magnetic saturation with means for varying the inductance to produce a substantial change in the effective resistance of the control system and at the same time maintain its resultant reactance substantially constant.

1,564,851—A. W. HULL, Schenectady, New York. Filed November 13, 1920, issued December 8, 1925. Assigned to General Electric Company. DYNATRON SYNCHRONOUS DETECTOR, in which a cathode and an anode are arranged within an evacuated vessel and a variable magnetic field produced therearound by the incoming signaling current.

1,564,852—A. W. HULL, Schenectady, New York. Filed September 9, 1921, issued December 8, 1925. Assigned to General Electric Company. ELECTRON DISCHARGE APPARATUS, in which the current through the device may be controlled by means of the grid electrode to perform any of the functions for which a three-electrode electron tube is adapted. When the magnetic field produced is properly proportioned, the device may possess several operating advantages over three-electrode devices of similar type, as previously operated. When such devices are employed as amplifiers, the degree of amplification which may be obtained depends upon the slope of the curve representing the relation between grid potential and output current. By the use of a magnetic field control in conjunction with the electrostatic field control the slope of this curve may, over a well defined operating range of grid potential, be greatly increased over its value in the absence of the magnetic field.

1,564,940—F. S. CHAPMAN, Greensburg, Indiana. Filed November 12, 1919, issued December 8, 1925. METHOD OF DETECTING THE PRESENCE AND APPROXIMATE LOCATION OF METALLIC MASSES by balancing a receiving system with respect to directively propagated signaling energy which is reflected by the hidden metallic masses which are to be discovered.

1,565,088—J. O. GARGAN, Brooklyn, New York. Filed September 22, 1922, issued December 8, 1925. Assigned to Western Electric Company. CONDENSER, in which the rotor plates are cast integral and move between stator plates which are also formed integral as a casting and where the rotor plates are tapered for securing a particular law of capacity variation.

1,565,092—H. C. HARRISON, Port Washington, New York. Filed June 23, 1921, issued December 8, 1925. Assigned to Western Electric Company. ATTACHMENT FOR OSCILLATION GENERATORS for mechanically controlling the selection for a desired frequency in an oscillation generator system.

1,565,150—J. W. HORTON, Bloomfield, New Jersey. Filed July 9, 1923, issued December 8, 1925. Assigned to Western Electric Company. OSCILLATION GENERATOR for developing oscillations of constant frequency of a higher degree of purity than is obtainable from the usual form of oscillation generator. In accordance with one modification of the present invention an oscillation generator, comprising a main amplifier having a regenerative feed-back circuit containing an auxiliary amplifier, is provided with two frequency determining circuits, one in the input circuit of the main amplifier and the other in the input circuit of the auxiliary amplifier. A step-down transformer couples the output circuit of each amplifier with the input circuit of the other amplifier, thereby tending to reduce the effect of the output circuit impedance of the amplifier upon the frequency determining circuit of the oscillator. A relatively low resistance in shunt to the low voltage winding of each step-down transformer tends to reduce the effect upon the main frequency determining circuit of the transformer impedance or the impedance of circuits associated with the transformer.

1,565,151—W. G. HOUSEKEEPER, New York City. Filed December 27, 1919, issued December 8, 1925. Assigned to Western Electric Company. ELECTRIC DISCHARGE DEVICE having automatic means for disconnecting the plate voltage supply system when the plate temperature becomes excessive.

1,565,152—W. G. HOUSEKEEPER, New York City. Filed November 28, 1920, issued December 8, 1925. Assigned to Western Electric Company.
VACUUM INSULATOR AND ITS ASSEMBLY for use in passing an electrical conductor through the wall of a high-power electron tube.

1,565,157—J. B. JOHNSON, New York City. Filed April 7, 1919, issued December 8, 1925. Assigned to Western Electric Company.
CIRCUIT ARRANGEMENT FOR DISCHARGE DEVICES, where a plurality of groups of parallel connected tubes are provided for feeding a common oscillation circuit.

1,565,200—H. T. Reeve, East Orange, New Jersey. Filed October 10, 1902, issued December 8, 1925. Assigned to Western Electric Company.
METHOD OF MAKING CORES FOR CATHODES OF VACUUM TUBES which comprises mixing metals including platinum and nickel and subjecting the mixture to heat treatment.

1,565,316—W. A. EATON, Arlington, Virginia. Filed March 25, 1920, issued December 15, 1925. Assigned to Radio Corporation of America.
METHOD OF AND APPARATUS FOR CONTROLLING ALTERNATING CURRENTS, particularly intended for signaling by means of an arc where only a single wave is radiated and the compensating wave suppressed. A radiating circuit and an idling circuit are provided upon which the arcs may be alternately operated during the production of signals without the radiation of a compensating wave.

1,565,351—H. S. DODSON and W. H. SHIREY, Detroit, Michigan. Filed July 26, 1922, issued December 15, 1925.
CONDENSER, in which a conical movable plate is arranged within a conical outer plate and the distance between the plates varied by axial movement of the condenser shaft.

1,565,416—L. W. CHUBB, of Edgewood Park, Pennsylvania. Filed February 14, 1921, issued December 15, 1925. Assigned to Westinghouse Electric and Manufacturing Company.
ELECTRON TUBE OSCILLATOR which comprises a plurality of plate elements, a source of electron emission and means included in an oscillatory circuit whereby an electron stream may be selectively controlled to impinge upon predetermined groups of the plate elements to cause the oscillations in the oscillatory circuit to be sustained.

1,565,478—D. G. LITTLE, Wilkinsburg, Pennsylvania. Filed April 6, 1923, issued December 15, 1925. Assigned to Westinghouse Electric and Manufacturing Company.
RADIO TRANSMITTER, including a plurality of electron tubes in which switching means are provided in the plate circuit of the tube for controlling the parallel connection of the tube for varying the effective circuit arrangement through said transmitting system.

1,565,505—F. M. RYAN, East Orange, New Jersey. Filed August 14, 1924, issued December 15, 1925. Assigned to Western Electric Company.
RADIO TRANSMITTER of high power in which control circuits are provided for starting the electron tube system by first energizing the cathodes of the tubes and then gradually energizing the anode circuit for bringing the transmitter into operating condition.

1,565,521—J. S. STONE and C. C. ROSE, San Diego, California and East Orange, New Jersey, respectively. Filed December 8, 1920, issued December 15, 1925. Assigned to American Telephone and Telegraph Company.
SECRET COMMUNICATION SYSTEM, which consists in dividing each of a plurality of message frequency bands into sub-bands, and translating each sub-band into corresponding radio frequency bands. The radio frequency bands are so arranged that sub-bands of different messages will be intermingled in the frequency spectrum, but may be selectively separated out for forming intelligible signals at the receiver.

1,565,530—P. THOMAS, Edgewood, Pennsylvania. Filed August 18, 1921, issued December 15, 1925. Assigned to Westinghouse Electric and Manufacturing Company.
MERCURY VAPOR SPARK GAP for use in the production of high

frequency oscillations in which an H-shaped vessel is provided having the lower portions of each of the uprights formed into pockets containing mercury with a spark discharge gap formed across the H portion of the gap.

1,565,544—R. BOWN, Wyoming, New Jersey. Filed September 18, 1924, issued December 15, 1925. Assigned to American Telephone and Telegraph Company.
RADIO TRANSMISSION SYSTEM having a circuit arranged to compensate for the changes in volume of the signaling current for maintaining reception at a distant station uniform regardless of variable conditions intermediate the stations.

1,565,562—T. R. GRIFFITHS, Dover, New Jersey. Filed February 21, 1925, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the filament of the electron tube is supported by a gripping device positioned around a central support through the tube.

1,565,569—W. G. HOUSEKEEPER, New York. Filed July 21, 1922, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE of high power construction in which the electrodes are mounted upon a central rod and the plate is formed in the shape of a metallic cup sealed to the glass vessel at the base.

1,565,570—W. G. HOUSEKEEPER, New York. Filed October 29, 1923, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the plate electrode comprises a cylindrical sheet of metal with a rib extending longitudinally thereof and a rod passing through the rib for supporting the plate with respect to the other electrodes.

1,565,595—W. O. SNELLING, Allentown, Pennsylvania. Filed February 28, 1923, issued December 15, 1925.
CURRENT-RECTIFYING DEVICE for use in detectors which is prepared by contacting a metal with the vapor of an element of the sulfur group at a temperature above the reaction temperature of the two materials, but below the temperature of fusion of the reaction product formed.

1,565,596—H. C. SNOOK, South Orange, New Jersey. Filed November 15, 1923, issued December 15, 1925. Assigned to Western Electric Company.
SIGNAL SYSTEM, wherein impulses of equal time duration are produced by a swinging pendulum which permits the passage of light upon a photo-electric cell for actuating an amplifier circuit connected therewith.

1,565,600—E. R. STOEKLE, Milwaukee, Wisconsin. Filed August 30. 1920, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE of high power construction, in which a metallic tubular anode surrounds the electrodes of the tube and is provided with glass end portions through which the leads to the electrodes pass.

1,565,603—R. F. TRIMBLE, Elizabeth, New Jersey. Filed October 4, 1918, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the electrodes are supported by means of an arbor anchored into the stem of the tube by wires estending out from the arbor.

1,565,659—J. E. LILIENFELD, Kew Gardens, New York. Filed September 3, 1921, issued December 15, 1925.
HIGH VACUUM DEVICE FOR INFLUENCING CURRENTS comprising an envelope evacuated to such a degree that ionization is substantially prevented, electrodes including an unheated cathode having an active surface or surfaces of small radius of curvature in close proximity to an anode for producing an electronic discharge and means for producing a separate field of force to modify the character of the discharge.

1,565,708—W. R. BULLIMORE, London, England. Filed October 11, 1922, issued December 15, 1925.
THERMIONIC VALVE having an arched cathode support therein, with a hollow grid having flat sides meeting along a curved edge disposed parallel to said filament, grid electrode being formed of looped wires

enclosing said filament. A sheet metal anode of similar shape is provided enclosing both the filament and the grid.

1,565,799—W. DUBILIER, New Rochelle, New York. Filed February 19, 1921, issued December 15, 1925. Assigned to Dubilier Condenser & Radio Corporation.

INSULATING STRUCTURE FOR HIGH POTENTIAL CONDENSERS, in which an insulator is supported in the head of a condenser casing in such a manner that losses due to puncture, creepage and brush discharge or corona effects are reduced to a minimum.

1,565,857—M. J. KELLY, New York. Filed June 30, 1921, issued December 15, 1925. Assigned to Western Electric Company.

VACUUM TUBE MANUFACTURE, in which the tubes are supported in inductance coils through which high frequency current is passed for inductively heating the electrodes of the tubes and removing occluded gases therefrom.

1,565,873—H. J. VAN DER BIJL, New York. Filed August 10, 1920, issued December 15, 1925. Assigned to Western Electric Company.

VACUUM TUBE AND METHOD OF OPERATING THE SAME by producing a narrow beam of rays from a cathode and placing an apertured body in the path of the rays with a screen for receiving the rays. The cathode, apertured body and screen, are surrounded by an atmosphere of gas at such a pressure that electrons discharged from the cathode produce a sufficient number of positive ions to overcome the defusion of the cathode ray beam.

1,566,162—DAVID H. MOSS, Newark, New Jersey. Filed (Original) February 9, 1924; (divisional) Mar. 4, 1925, issued December 15, 1925. Assigned to Brandes Laboratories, Incorporated.

METHOD FOR MAKING SUPPORTS FOR SOUND REPRODUCERS, in which the parts for a loudspeaker are manufactured by pressing and punching operations and with the parts designed for assembly in large numbers for uniform operation. This is the patent covering the method of making the Brandes Table Talker.

1,566,243—Q. A. BRACKETT, Springfield, Mass. Filed September 2, 1921, issued December 15, 1925. Assigned to Westinghouse Electric & Manufacturing Company.

RADIO TELEPHONE SYSTEM, in which an oscillation generator system is modulated by means of a variable space current device which is filled with hydrogen gas for decreasing the temperature variations necessary for effective modulation.

1,566,293—H. J. VAN DER BIJL, New York. Filed September 4, 1919, issued December 22, 1925. Assigned to Western Electric Company, Incorporated.

THERMIONIC DEVICE, in which the electrodes are supported by wires which pass through and are sealed in the horizontal glass rod member.

1,566,469—J. F. FARRINGTON, New York. Filed December 23, 1920, issued December 22, 1925. Assigned to Western Electric Company.

TWO-WAY COMMUNICATION SYSTEM for the simultaneous transmission and reception of signals without interference of the adjacent transmitting circuit upon the receiving circuit. The effect of the outgoing signals upon the receiving circuit is neutralized by a connection of the oscillator with the receiver in an opposite sense.

1,566,634—H. P. TRAMBLEY, San Francisco, California. Filed June 18, 1923, issued Dec. 22, 1925.

APPARATUS FOR TREATING DISEASE, including an oscillatory electron tube circuit with electrodes by which high frequency oscillations may be impressed upon the body.

1,566,657—W. T. DITCHAM, Lebanon Park, England. Filed December 18, 1920, issued December 22, 1925. Assigned to Radio Corporation of America.

RADIO TRANSMITTER, in which signals are produced by shunting

a resistance interposed between the source of supply and the electron tube oscillator of the radio transmitter.

1,566,680—A. MEISSNER, Berlin, Germany. Filed September 3, 1921, issued December 22, 1925. Assigned to Gesellschaft fur Drahtlose Telegraphie M.B.H. Hallesches.
SENDING ARRANGEMENT where an antenna circuit is provided with a plurality of grounded loop circuits for preventing the radiation of harmonics from the transmitting station.

1,566,928—M. C. RYPINSKI, New York. Filed March 4, 1925, issued December 22, 1925. Assigned to Brandes Laboratories, Incorporated.
LOUDSPEAKER having a plurality of sound reproducing diaphragms each of which are efficient for a particular range of tone frequencies. The diaphragms are operated simultaneously from the same electromagnetic mechanism for efficiently reproducing sound over a broad range of tone frequencies.

1,567,067—J. F. LINDBERG, Chicago, Illinois. Filed July 20, 1922, issued December 29, 1925. Assigned to Reliance Die & Stamping Company.
CONDENSER, in which a set of stationary plates in the form of concentric cylinders are interleaved by a set of similarly arranged movable plates which are axially adjustable in the direction of the stationary plates.

1,567,068—J. F. LINDBERG, Chicago, Illinois. Filed (original) April 17, 1922: (divisional) January 26, 1924, issued December 29, 1925. Assigned to Reliance Die and Stamping Company.
ELECTRIC CONDENSER constructed of flattened coiled sheets of dielectric material and sheet metal. The sheet metal surrounds the dielectric material and forms one side of the condenser and a flat sheet of metal is provided forming the other side of the condenser.

1,567,204—J. S. STONE, San Diego, California. Filed January 29, 1925. issued December 29, 1925. Assigned to American Telephone & Telegraph Company.
RADIO TRANSMITTING SYSTEM, in which two transmitters and two receivers, operating on the same frequency, are provided with a secondary relay station, each receiver being rotated at a point where the waves build up from one transmitter, while the relay station is located at a point where the waves are substantially null for increasing the transmission range of a radio system.

1,567,260—W. GARITY, Brooklyn, New York. Filed March 17, 1923, issued December 29, 1925. Assigned to De Forest Radio Telephone & Telegraph Company.
AUDION ELECTRODE STRUCTURE, wherein a plate electrode is blanked out from a flat sheet of metal and rolled into a cylindrical electrode.

1,567,293—E. PFIFFNER, Fribourg, Switzerland. Filed April 7, 1923, issued December 29, 1925.
ARRANGEMENT FOR PREVENTING MARGINAL DISCHARGES by providing margins of a great electric resistance and by making the condenser independent from the marginal discharges.

1,567,409—A. E. BERDON, Detroit, Michigan. Filed May 29, 1922, issued December 29, 1925.
CONDENSER particularly arranged for connecting radio receiving equipment with lamp sockets in which insulated bushings are provided having an entrance for the power line and an outlet for the connection to the receiving set with a condenser disposed between the bushings.

1,567,542—G. W. PICKARD, Newton Center, Mass. Filed June 30, 1921, issued December 29, 1925. Assigned to Wireless Specialty Apparatus Company.
CLOSED TUNED COIL OR LOOP AERIAL for direction finders, in which two loops are arranged at right angles to each other, with a magnetic field which coincides with the direction of the transmitted waves located within the looped conductors

1,567,544—I. P. RODMAN, Newark, New Jersey. Filed March 8, 1924, issued December 29, 1925. Assigned to Garod Corporation.
INSULATOR STRUCTURE FOR ELECTROSTATIC CONDENSERS AND THE LIKE, in which the stator plates are supported on insulated columns carried at opposite ends by pointed members extending through the end plates of the condenser.

1,567,562—H. H. YOUNG and E. A. RYDER, Keyport, New Jersey. Filed March 26, 1924, issued December 29, 1925.
SUPPORT FOR ELECTRICAL APPARATUS for radio receiving sets, in which the tuning condensers are interposed between the electron tube sockets, the tuning condensers forming walls between the sockets and providing means for supporting the socket members in a relatively small unit construction.

1,567,565—Q. A. BRACKETT, Pittsburgh, Pennsylvania. Filed March 30, 1921, issued December 29, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RECEIVING SYSTEM having an amplifying system included as an element in a balanced circuit, the resistance of the amplifier being changed by the received signal to unbalance the receiving circuit for securing resonance to incoming signalling energy.

1,567,566—Q. A. BRACKETT, Pittsburgh, Pennsylvania. Filed April 12, 1921, issued December 29, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RECEIVING SYSTEM for detecting signal current in which a local audio-frequency circuit is unbalanced by the incoming signaling energy for actuating a responsive device.

1,567,567—Q. A. BRACKETT, Pittsburgh, Pennsylvania. Filed April 18, 1922, issued December 29, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO RECEIVING SYSTEM for the reception of undamped wave signals without the employment of a heterodyne by means of a balanced circuit arrangement which is disturbed from normal balance by incoming signaling energy for actuating a telephone receiver.

1,567,734—R. A. HEISING, East Orange, New Jersey. Filed October 1, 1919, issued December 29, 1925. Assigned to Western Electric Company.
RADIO TRANSMISSION SYSTEM for the duplex transmission of radio telephone messages, where transmission is carried on at one wavelength and reception at another wavelength without interference of the transmitter upon the receiver.

1,567,764—J. SLEPIAN, Wilkinsburg, Pennsylvania. Filed April 21, 1921, issued December 29, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO RECEPTION, in which the signal current operates to change the amount of unbalancing in a plurality of directions in a Wheatstone bridge across a diagonal of which a local source of high frequency alternating current is connected.

1,567,848—L. L. KUMEILIKE, Napa, California. Filed March 9, 1922, issued December 29, 1925.
RADIO FREQUENCY TRANSMISSION SYSTEM particularly adapted for signaling by means of an arc where an intermediate un-tuned loop circuit is coupled to the oscillatory and antenna circuits, by which the power may be balanced and the antenna de tuned in the production of signals.

1,567,850—DAVID HENRY MOSS, NICHOLAS J. CELENZA and WILLIAM H. GERNS, of Newark, New Jersey, Brooklyn, New York, and East Orange, New Jersey, respectively. Filed March 20, 1925, issued December, 29, 1925. Assigned to Brandes Laboratories, Incorporated.
TERMINAL BLOCK AND CONNECTIONS FOR TELEPHONE RECEIVERS, in which rigid mechanical connections and good electrical contact may be made between the flexible cords leading to the external electrical circuit, an electrostatic shield surrounding the conductors, and the electromagnets and case of the telephone receivers.

1,567,928—H. F. ELLIOTT and J. A. MILLER, Palo Alto, California. Filed January 9, 1922, issued December 29, 1925. Assigned to Federal Telegraph Company.
RADIO FREQUENCY SYSTEM having an arc converter for the transmission of signals with a tuned circuit in series with the arc and impedance also in series with the arc and a load circuit closely coupled to the impednace and a resistor connected in parallel to the impedance for the stabilized operation of the arc transmitting system.

1,567,978—F. G. NIECE, Cleveland, Ohio. Filed March 24, 1920, issued December 29, 1925.
ROTARY SPARK GAP, in which spark electrodes are rotated past a plurality of stationary circuits for securing high frequency discharge. A construction of spark gap is provided where the rotor extends between two adjacent stators and a spark discharge path established therebetween when the electrodes are aligned.

1,568,026—J. B. ZETKA, Nutley, New Jersey. Filed June 24, 1924, issued December 29, 1925. Assigned to Brightson Laboratories, Incorporated.
ELECTRON DISCHARGE DEVICE, iu which a spring device is provided for supporting the filament under tension for preventing short circuit between the filament and the other electrodes within the tube structure.

Re 16,231—E. E. CLEMENT, Washington, D. C. Re-issue filed July 7, 1925, issued December 15, 1925. Assigned to Edw. P. Colladay.
RADIOPHONE SYSTEM, in which a broadcasting station transmits to a plurality of subscribers each having receiving circuits connected by line wire with the broadcasting station for enabling the operator at the broadcasting station to know the condition of operation of each of the subscriber circuits.

Des. 68,686—C. D. WHITE, East Orange, New Jersey. Filed August 29 1925, issued November 20, 1925. Assigned to Brandes Laboratories Incorporated.
DESIGN FOR A CABINET TYPE RADIO REPRODUCER, having a horizontal cabinet behind which a sound amplifying horn is mounted connected with an electromagnetic driver.

Des. 68,898—STEPHEN BOURNE, New York. Filed July 27, 1925, issued December 1, 1925. Assigned to Brandes Laboratories, Incorporated.
DESIGN FOR A LOUDSPEAKER, where the base of the loudspeaker is cast in an ornamental shape and provides means for supporting an electro-magnetic driver therin.

Des. 69,004—LE ROY W. STAUNTON, Jackson Heights, New York. Filed December 12, 1924, issued December 8, 1925. Assigned to Brandes Laboratories, Incorporated.
DESIGN FOR A LOUDSPEAKER RADIO REPRODUCER, in which the electromagnetic driver is mounted within an ornamental cabinet from which the reproduced sound emanates.

Obituary

Dr. Harold W. Nichols, Fellow of the Institute, died at his home in Maplewood, New Jersey, on November 14, last. Dr. Nichols was born in Iowa, on February 23, 1886. He gained his technical education at the Armour Institute of Technology, Chicago, from which institution he received the B.S. degree in 1908, and E.E. in 1911. From the University of Chicago he received the degrees of M.S. and Ph.D.

At the time of his death, Dr. Nichols was a Manager of the Institute, and had been for several years an earnest and valuable worker on important committees. At the October, 1925, meeting of the Board of Direction his name was placed in nomination for the Presidency of the Institute. His untimely death is deeply regretted by his associates on the Board of Direction.

George Y. Allen, a Member of the Institute, died on November 12, last, as a result of injuries received in a train wreck in New Jersey. Mr. Allen was born at Bernardsville, New Jersey, in 1893, and graduated from Stevens Institute of Technology, Hoboken, New Jersey, in 1915 with the degree of M.E. After graduation he was engaged in research work for the Western Electric Company, and at the outbreak of the late war was appointed radio aide to the U. S. Navy Engineering Bureau. In 1919 he entered the service of the Westinghouse Electric and Manufacturing Company, New York, and at the time of his death was assistant to the manager of the radio department of that company.

Mr. Allen served the Institute on several active committees in recent years, and at the time of his death was returning from the Fourth Annual Radio Conference called at Washington by Secretary Hoover.

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 14 APRIL, 1926 Number 2

CONTENTS

GENERAL INFORMATION

The PROCEEDINGS of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings and at the Sections in the several cities listed on the following page.

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Subscriptions to the PROCEEDINGS are received from non-members at the rate of \$1.50 per copy or \$9.00 per year. To foreign countries the rates are \$1.60 per copy or \$9.60 per year. A discount of 25 per cent is allowed to libraries and booksellers.

It is understood that the statements and opinions given in the PROCEEDINGS are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole

PUBLISHED BY

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INSTITUTE ACTIVITIES

February Board Meeting

At the meeting of the Board of Direction, held on February 8, the following were present: Donald McNicol, president; Ralph Bown, vice-president; W. F. Hubley, treasurer; Lloyd Espenschied, A. H. Grebe, L. A. Hazeltine, R. H. Marriott and L. E. Whittemore, managers.

The Board reappointed Dr. A. N. Goldsmith secretary, and Mr. W. F. Hubley treasurer, for the year 1926.

Due to growth of the Institute it was decided to procure larger space for the headquarters offices. In place of the room heretofore occupied at 37 West 39th Street, a suite of five rooms was leased on the fifth floor of the same building, occupied on March 1, 1926.

Mr. H. M. Turner was appointed as the Institute's representative on the Dry Cell Committee, Radio Sectional Committee, A. E. S. C. Louis A. Hazeltine was appointed Institute representative on the Radio Advisory Committee, Bureau of Standards, Department of Commerce.

Mr. Whittemore presented a report summarizing the action taken at a Conference on Drawing and Drafting Room Practice, called by a joint committee of engineering societies on December 4, 1925.

Memorial to Dr. Goldsmith

At the first session of the 1926 annual convention in New York, an engrossed memorial was presented to Dr. Alfred N. Goldsmith, secretary of the Institute, and from the beginning, editor of the PROCEEDINGS. The memorial was signed by all of the officers and was presented to Dr. Goldsmith by retiring President J. H. Dellinger.

Applications For Membership

It is learned that applicants seeking entry into the Institute are in some instances deterred by the requirement that references must consist of five Fellows, Members or Associates, for the respective grades. In some instances applicants do not

personally know five members to whom they may refer. There is a clause in the Constitution which states that in such cases the applicant may give as references other engineers, employers, or business associates who are not members of the Institute, provided they state on their applications that they are not acquainted with the stipulated number of members. This refers particularly to those applying for the Associate grade. Those applying for transfer to Member or Fellow grade should be able to refer to the required number of Fellows or Members.

Membership Certificates

Engrossed Diplomas are now available for Fellows and Members of the Institute, and membership cards for Associates. The Diplomas will be signed by the President and Secretary, and the cards by the Secretary. In each case the certificate is issued without charge to those applying for it. As it is desired to have the Diplomas signed by the President in office at the time election or transfer was approved by the Board, there may in some cases be a little delay in forwarding the document. Where the delay or inconvenience would be considerable in procuring the signature of the past-president, the president in office at time request is received for the Diploma may sign the form.

San Francisco Section

Professor Louis A. Hazeltine, manager, was present at a dinner arranged by the San Francisco Section, in January. Chairman J. F. Dillon, of the San Francisco Section, is accomplishing commendable results in building up the activities of the Institute on the Pacific Coast.

Growth of Membership

At the February meeting of the Board of Direction 105 applications for Associate grade were approved, and at the March meeting 160 applications were favorably acted upon. It is anticipated by the end of the present year the Institute will have 4,000 members of the various grades. Six thousand copies of the PROCEEDINGS are now printed of each issue.

Advertising Pages

The support given the Institute by radio companies advertising in the pages of the PROCEEDINGS warrants due recognition by the membership. When writing to advertisers it is of advan-

tage to mention that the advertisement was noted as appearing in the Institute's periodical.

Washington, D.C., Section

Regular and enthusiastic meetings are being held by the Washington Section. At the annual meeting Dr. A. Hoyt Taylor was re-elected chairman and Mr. T. Parkinson, secretary-treasurer. The Meetings and Papers Committee consists of Messrs. F. P. Guthrie, Chairman; Capt. Guy Hill, C. Francis Jenkins, and, ex-officio, the secretary-treasurer. At a recent meeting an informal talk was given by Dr. L. W. Austin, on "Some Notes on Radio Development in Europe."

Radio Relics

In response to the call for radio relics, several communications have been received. Professor R. A. Fessenden has submitted for deposit in the Institute's archives a package of documents dealing with the early history of the radio telephone, and Dr. A. E. Kennelly has presented a file of documents and photostat copies of papers which record announcements of the theories of the Kennelly-Heaviside Layer.

Canadian Section

The Canadian Section (Toronto) held a meeting on the evening of February 19, at which the following papers were presented: "The Design of Modern Broadcast Receivers," by Prof. A. M. Pacent; "Stepping Stones in Radio History," by D. Hepburn, and "The Panatrope," by C. L. Richardson. The meeting was held in the Auditorium of the Ward Street Works, Canadian General Electric Company.

On February 25, Messrs. C. L. Richardson and A. M. Pacent attended a meeting of the Radio Listeners' Association, Hamilton, Ont., where they delivered addresses on radio.

Rochester, N. Y., Section

A Section of the Institute has been organized at Rochester, N. Y., the first meeting being held on February 21.

The officers of the Section are: Chairman, Virgil M. Graham; Vice-Chairman, Joseph Hitchcock; Secretary-Treasurer, Harvey Klumb. The new Section started with a membership of forty, with additional applications to be passed upon.

A technical meeting was held on March 26.

Membership Committee

A meeting of the Membership Committee was held at Institute headquarters on the evening of February 23, the following being present: H. F. Dart, chairman, and Messrs. M. Berger, C. M. Jansky, Jr., W. G. H. Finch, Arthur Nilson, E. R. Shute and L. E. Whittemore. President McNicol was present, ex-officio.

The committee is perfecting plans for carrying on an active campaign looking to enrollment of all persons eligible to membership in the Institute who desire to avail themselves of the privileges and advantages of such membership.

Standardization Committee

For the purpose of avoiding duplication of effort, and to foster cooperation in the interests of radio engineering and radio manufacture, the following engineers have been made members of the Institute's Standardization Committee: A. J. Carter, as representative of the Radio Manufacturers' Association, Chicago, and R. H. Manson, as representative of the Associated Manufacturers of Electrical Supplies, New York.

Mr. L. E. Whittemore is chairman of the committee.

Elected to Member Grade

At the February and March meetings of the Board of Direction the following were elected to Member grade: Arthur H. Halloran, W. E. Garity, H. J. J. M. de R. Bellescize, Gerald M. Best, Leonard H. Bouchier, Archibald E. Hart, H. A. McIlvaine, J. P. McKenzie, James J. Nolan, W. L. Tierney, James E. Smith, E. Marks, Harrie King, Ira. F. Julian, W. W. Harper, J. M. Goodman, Charles S. Demarest, A. F. Bulgin, William Wilson, Arthur H. Lynch, Paul Kloke, H. F. Dart, L. J. Dunn, J. O. Smith, W. W. Lindsay, David H. Gage, John B. Ferguson and U. B. Ross.

American Association for the Advancement of Science

By virtue of the recent affiliation of the Institute with the American Association for the Advancement of Science, all Institute members may join the latter Association without payment of the usual entrance fee of $5.00. This privilege is extended for all of this calendar year, after which the same privilege is available only to new members of the Institute and

is available to them any time within a year after their election to the Institute.

The American Association for the Advancement of Science is the leading general scientific organization in America. Its annual meeting, held in a different city in December each year, is a meeting place of all the sciences. Its members receive either "Science" (a weekly) or the "Scientific Monthly." "Science" is a good medium for the publication of short scientific contributions on the results of research in the radio field when of interest to workers in the broader fields of science.

Seattle Section

The Seattle Section, at a recent meeting, had a paper by Mr. J. R. Tolmie on the subject of "Modulation." Mr. John Greig described the method of carrier suppression in transatlantic radio telephony, and Mr. Libby gave an outline of the results of the 1925 radio conference at Washington.

Bound Volumes of PROCEEDINGS

Bound volumes of the Institute PROCEEDINGS are available for the year 1917 and all years to 1925 inclusive. The price to members is $8.75 per volume; to non-members $11.00 per volume.

ERRATA*

Corrections for February, 1926, issue of the PROCEEDINGS:

Page 87: Equation should read:

$$\Delta d = \sqrt{y^2 + 4h^2} - y.$$

Page 92: Equations (9), (10), (11) and (13) should read:

$$\theta_1 = 2\pi \int_o^t [F_o + f \sin r(t - d_1/V)]dt \tag{9}$$

$$\theta_2 = 2\pi \int_o^t [F_o + f \sin r(t - d_2/V)]dt \tag{10}$$

$$\begin{aligned} \Delta\theta = \theta_1 - \theta_2 = 2\pi \int_o^t F_o\,dt + 2\pi \int_o^t f \sin r\,(t - d_1/V)\,d_t \\ -2\pi \int_o^t F_o\,dt - 2\pi \int_o^t f \sin r\,(t - d_2/V)\,dt \end{aligned} \tag{11}$$

$$\begin{aligned} \Delta\theta = \frac{2\pi f}{r} [(\cos rt - 1)\,(\cos r d_2/V - \cos r\,d_1)\,V + \\ \sin rt\,(\sin r d_2/V - \sin r d_1/V)]. \end{aligned} \tag{13}$$

Delete (12)

* Manuscript received by the Editor, November 15, 1925. Presented at a meeting of the INSTITUTE OF RADIO ENGINEERS, New York, November 4, 1925.

TRANSMISSION AND RECEPTION OF PHOTORADIOGRAMS*

By

Richard H. Ranger

(Radio Corporation of America)

Introduction

From recent announcements it may seem to many that the art of picture transmission has suddenly been born; but it is as old as the communication art itself. The transmission of pictures electrically had its inception almost at the same time as straight telegraphy, for in 1842 Alexander Bain, an English physicist, first proposed a device to send pictures from one place to another by electric wires. His plan is so basically correct that it is only right at the start to show the simplicity of his plan and how, generally, we are all following in his footsteps. He had, as is seen in Figure 1, two pendulums which were arranged electrically in

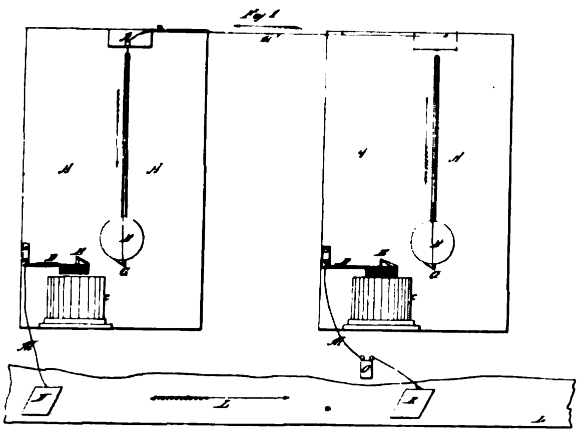

Figure 1—Copy of Bain's Original Patent

such a manner that if one preceded the other by a slight amount of the time of a stroke it was held until the other had reached the same position, when both then started a new stroke. These swinging pendulums were the basic synchronizers which

*Presented before The Institute of Radio Engineers, New York, June 3, 1925. Received by the Editor, October 5, 1925.

are necessary in any picture work. On each swing, a tablet descended a notch at a time at the side of the pendulum. At the transmitting station the swinging arcs of the pendulum carried a small contactor which rode over type faces making the appropriate electric contacts to be transmitted to the distant receiver where a similar swinging pendulum was tracing a path across a piece of paper. By chemical action, the electricity received from the transmitter would discolor the paper at the receiver to give an impression of the original.

We have here the basic elements of all picture transmission. First, the synchronous action covering a surface point-by-point at both transmitter and receiver, and the electrical identification of the point value to correspond between transmitter and receiver.

As it has taken more then eighty years from this initial step to anything approaching commercial reality, there must be something basically difficult in the process.

There have certainly been one thousand workers in the field, and surely it would seem that all of the fundamental conceptions of solving the problem had been realized by this time. However, it is safe to say that present successes are largely due to the wonderful strides that have been made in recent years in the production of more accurate instruments, which have given present-day workers in this field a far greater storehouse from which to draw upon in the accomplishment of the problem. Naturally many transmissions of pictures have been made and successfully, too. The fact that ours may have gone greater distances is only because that is what we were requested to do.

The Start

Mr. Owen D. Young, Chairman of the Board of Directors of the Radio Corporation of America stated, at a banquet, that he was tired of all the arduous effort behind a twenty-four-hour job of sending radio messages by telegraphy from a transmitting operator to a receiving operator who put down the letters one by one at a distant point. Instead of this, the new possibilities of radio should make it feasible for us to say: "*ZIP*, and a page of the *London Times* is in New York City." "Not being an engineer," he added, "I am not interested in the details; that is your job." If he had perhaps known, or if we had ourselves known, of all the griefs that others had gone through, perhaps we might have hesitated treading on such fearful ground. But, fortunately for us, our knowledge of the basic art developed apace with our study

of the problem, and we found ourselves living through all the past lines of thought of these many investigators, in rapid succession.

Figure 2 is a Denison facsimile of telegraph tape taken in 1901. Figure 3 is an example of the Korn system taken in 1922. Figure

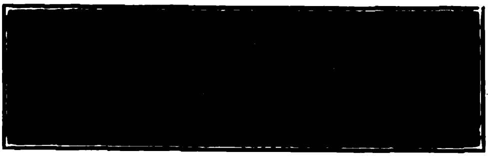

FIGURE 2—Denison Facsimiles of Telegraph Tape

4 shows the result of the Belin system transmitted in 1924, and Figure 5 is an example of the Jenkins process in the same year. Figure 6 represents the Ferree process in 1924, Figure 7 the Bart-Lane system in 1922, and Figure 8 the A. T. & T. Co. in 1925.

FIGURE 3—A Picture of Mr. Korn that was sent from Munich to Rome by the Korn System, 1922

FIGURE 4—A Picture of General Pershing that was sent by Belin's Asycerations

ECONOMICS

In view of the widely diversified attacks on the problem previously we soon realized that our main work was to produce an economic solution rather than essentially the purely mechanical problem of producing a machine that would work.

It has taken 80 years from the first inception to come to commercial operation due to the fact that it is inherently a more dif-

ficult proposition to send a picture than it is to send a telegraph message, or the voice.

Picture transmission requires exactly what these two other transmissions do, which is to depend on an intensity variation

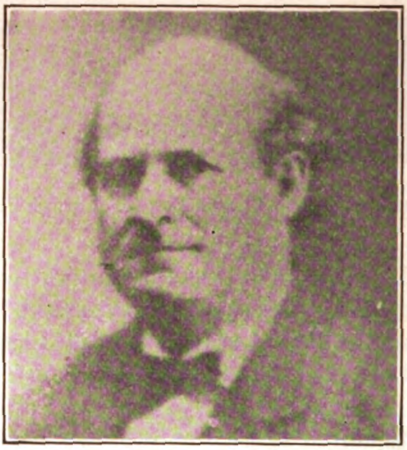

FIGURE 5—A Picture of William Jennings Bryan that was Transmitted by the Jenkins' System in 1924

with time; but it must do the additional job of indicating the points on an area for which these values must be represented. Furthermore, whereas with the eye a whole picture is taken in at a glance,

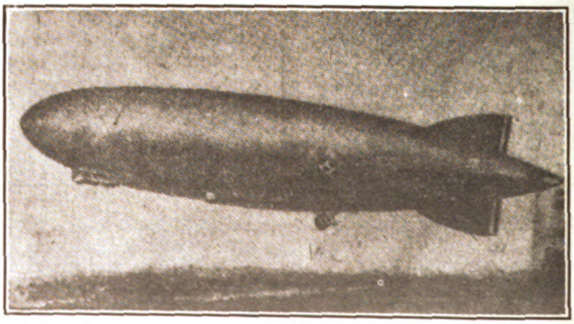

FIGURE 6—This Picture was Transmitted by the "Ferree" System in 1924

due to the fact that there are separate eye nerves for each portion of the area covered in the picture, in communication channels we are naturally restricted to taking a point at a time for each communication channel. If there happens to be more than one communica-

tion channel available, naturally more than one point can be taken at a time. But communication channels, that is, wires or radio circuits, are not available in such large numbers as to permit joint operation over several. Usually, it has seemed wiser to try to get the most out of one channel only. This means, therefore, that it takes a measurably greater time to cover a picture from point to point.

Two Lines of Attack

In order to keep a fresh viewpoint at all times and not to get into a cul de sac with any single one, it has always been our plan

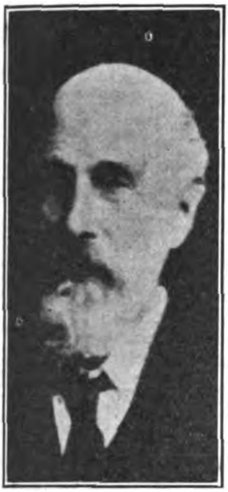

Figure 7—Sample of Cable Picture Transmission by the Bart-Lane System, 1922

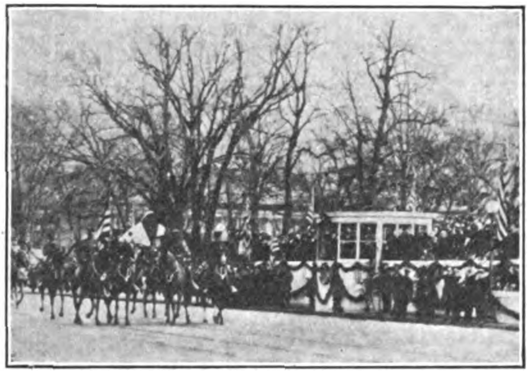

Figure 8—One of the Views of the Presidential Inauguration that was Transmitted from Washington to New York by the A. T. & T. System in 1925

to have two methods on trial for each essential of the picture development. It has been the old story of "the survival of the fittest." It takes will-power to throw away the results of months of work and time and money, when it is evident that a line of attack does not have the earmarks of success. But having two lines of attack at all times, we have realized this perhaps a little more readily, and as a result have built up quite a graveyard of dead ideas, and we trust a living survivor of merit.

Picture Shorthand

Morse's wonderful contribution to communication was not alone, as most seem to think, the development of a telegraphic

machinery or equipment, but largely the development of the telegraph code. Any number of telegraph devices had been constructed before Morse, but they did not have the economic practicability of an all-round system which would get words across in a short space of time.

How successful Morse was may be realized when, today, it is an established fact that the Morse code, representing letters by the dots and longer dashes, is still the most economical way of getting a given amount of words from one point to another, in the shortest time, with the least power, over the greatest distance, and through the greatest amount of interference.

Of course other means of sending words have been produced, typically, the telephone; but it requires, as you may all well realize, a higher quality of wire service and perfection in apparatus to accomplish the higher speeds realized in words transmitted by the voice. The same thing is true of many other systems proposed and in use wherever better facilities are available.

As soon as we realized the economic angle of our problem we began to look for a picture shorthand. It may well be mentioned at this time that our whole problem was largely one of realizing what confronted us and what our real aim was and then the answers began to come easily.

Practically every system to date has been, and still is, on the basis of dividing the picture up into small unit areas and to transmit their values one after the other. This is exactly the plan that would occur to any one knowing the success of the usual half-tone process of printing a picture as in a newspaper. Figure 9 shows this half-tone effect, and it will be seen that there is a regular grading in the proportionate size of the little squares to the surrounding area from the lightest portion to the darkest. Naturally a picture transmission system which would duplicate this would seem to be all that was necessary. But when we realize that the usual newspaper half-tone (and none too good a one at that) has at least 65 dots in a row for an inch, or more than 4,000 of them to a square inch, the size of the job becomes apparent. Let us assume that we wish five tone values to each of these dots, we may then describe this, arbitrarily, as requiring five photo units for each of these dots, or some 20,000 photo units to the square inch. In other words, it requires the ability to transmit from one point to another in identifiable shape 20,000 photo unit pulses per square inch. Naturally, this can be done on any circuit if you have time enough, and if it is a particularly good circuit it can be done in a very short time. The ratio between

the speed of transmission available and this quantity of units is the limiting factor.

On high-class telephone circuits we can readily send 200 such photo units in a second; but in the usual telegraph circuits such speeds are quite difficult, the fastest usual speeds being some 75 separate pulses a second, and normally around 30 or 40 impulses a second. The telegraph circuit, wire or radio, is a slower moving but further carrying message channel.

It is thus seen that, analyzing in this way, the usual method of picture transmission has found its serious drawbacks in the number of pulses that have to be put through; and the precision

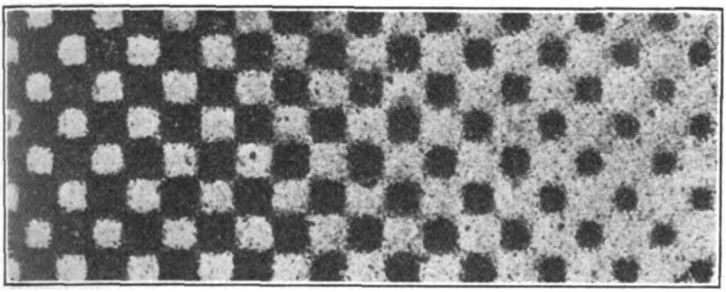

FIGURE 9—A Fundamental Specimen of "Korn's" Work in 1922

with which they have to be put through; and the time that it takes to put them through.

Search for a shorthand method of accomplishing the same results was then started. Our first effort in this direction consisted in the variable dot-spacing method. Obviously, if we place a group of dots on a piece of white paper and space them widely, we will get an impression of practically white. If we place them close, we approach black. This is what we did in our first shorthand attempt, making each dot of generally the same size; although it worked out practically such that the individual dots widely spaced were a little lighter than those grouped together. These dots by their grouping constituted the shades of the picture. The dots were so chosen that in size they would occupy a space of approximately one-fourth of the 64th of an inch as being the usual newspaper standard. One such dot per 64th of an inch would then give an impression of gray color. If they were spaced further apart, this gray color would give way to white. If they were spaced closer together, the gray would become darker up to almost black for the deepest portions. The spacing then was approximately two to each 64th of an inch.

Under these conditions it is realized that we have gone from the necessary five values for each 64th of an inch of the older systems to two values for each 64th of an inch, and have therefore realized a shorthand of a ratio of approximately five to two. Naturally we had the idea of what we wanted in the way of this dot concentration before we had the actual means for accomplishing it, but we were not long in finding a circuit which would give us this photographically and automatically.

Dot-Dash Plan

Not satisfied with the shorthand already accomplished, we carried the process a step further. Now we start from separately grouped dots in the white end of the scale, and come up to the densely concentrated dots as before. But this time the receiver drum is given twice the speed of the movement, so that the spacing which formerly gave almost a black, now gives a middle gray. Then to accomplish the further deepening to the black, we lengthen out each of the dots grouped closely together so that they become heavier and heavier, and finally for solid black we have the transmitter held constantly. Many adaptations of our first plan could be suggested, but after trying many we came to a few, one of which consists of a balanced arrangement such as many are familiar with in the usual push-pull type of amplifier. In Figure 10 one side of the outfit works in the progression from white to gray and the other side works in the light progression from gray to black, with a slight overlap at the center.

The reduction that this shorthand accomplishes over the previous method is 2 to 1, so that, over all, a 5 to 1 improvement has been made. This means that with a fixed available speed for the transmission of individual units, by this process five times the area can be covered in the same length of time. Furthermore, a wide range of tones is secured without abrupt changes from one tone to the next. The individuality of the alignment of the sharp edges can be made very precise providing the synchronizing of the motors is sufficiently accurate.

And what interested us more than anything else was that we seemed to be entering on a new form of art. No doubt many will look on this as rather a bold expression, but it is the very boldness of our pictures which carries them across. While it is true that they leave considerable to the imagination, this is inherently true of art, and it is an interesting thing that the more that one sees of this type of picture the more one sees in any

given example. Naturally, when the pictures are reduced in size, the artistic effect is greatly enhanced.

Photography

In such a development it is natural that those who see only the general effects of the work may not appreciate the effort that must be expended on all the details involved. And if I may be allowed to mention one briefly, it is the production of a good film at the transmitter. We have found in our work that a film

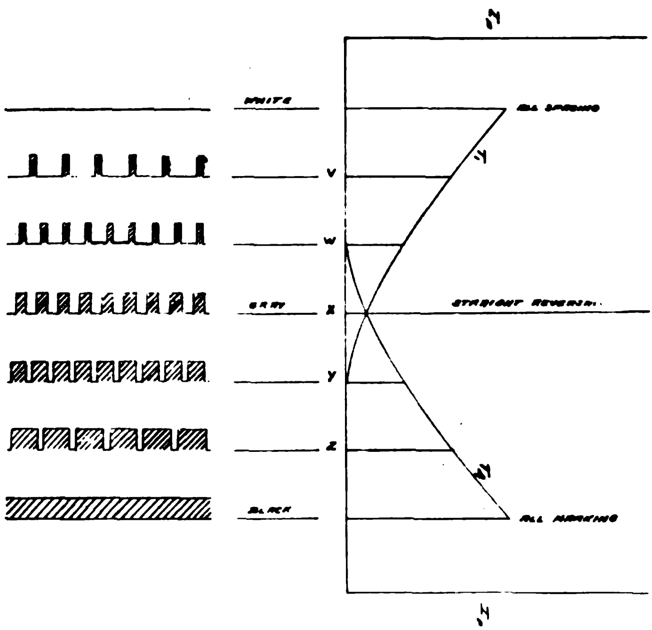

Figure 10

that would be normally classed as thin, is the best for our purposes. In actual measurements we have found that a film which varies in its ability to transmit light from 25 per cent. at the darkest portions, to 80 per cent. at the lightest portions, gives us best results. Naturally, it would be by chance that a film produced in the usual manner would be of a value best suited for transmission.

To organize our operations on a practical basis we have therefore made a very extensive study of photographic copying. We have found, for example, that with a given fixed original, it is possible to get a wide variation in the transparency of the copy from this original by changing either the exposure time in

our copying camera, or the development time. Also it is possible to get a still wider variation by using different types of films. These facts have, of course, been known, but mostly in a rule of thumb way. Curves have been developed which show the effect of changing the time of exposure in seconds, with a constant development; the effect of changing the time of development in minutes, with a given exposure; the effect of changing to a different film giving a very flat contrast; also other curves, accentuating the contrast.

From these curves as a starting point it is possible to obtain a wide range of values by proper selection. These have all been classed in the five sets of curves about a particular point to show just how the variations can be obtained. (Figure 11). For example, we will suppose that the original from which we are to

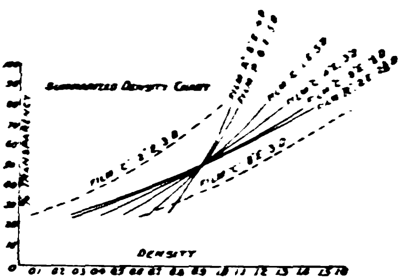

FIGURE 11—Summarized Density Chart

make a copy centers about a value of nine-tenths in density. It is then seen that if it already covers a wide range of values from this as a center, we can use a flat curve with a two-second exposure and 2¾-minute development. If it covers a less range, we can use a different type of film with eight seconds of exposure and 1½-minute development. The same type of film can be modified by giving it a shorter exposure and in turn, a longer development, to make the curve take up different positions, and finally, by using a special slow-process film, we can obtain the required transparency with only a very slight density change available in the original. Naturally, it would not always be possible for the original film to center about a point such as nine-tenths, and we have therefore also shown on this curve how the whole process may be moved to the left or to the right by changing the exposure and using the same development. This information has been drawn up in a single table, so that the practical operator can obtain from any given original the copy which will have the exact range desired.

9. First Apparatus

We will now come to the concentration of the apparatus we use. Basically, we must start with a photograph. This photograph is conveniently in the form of a film such that it may be placed around a glass cylinder, as shown on the picture of the original transmitter, Figure 12. A powerful light is on the

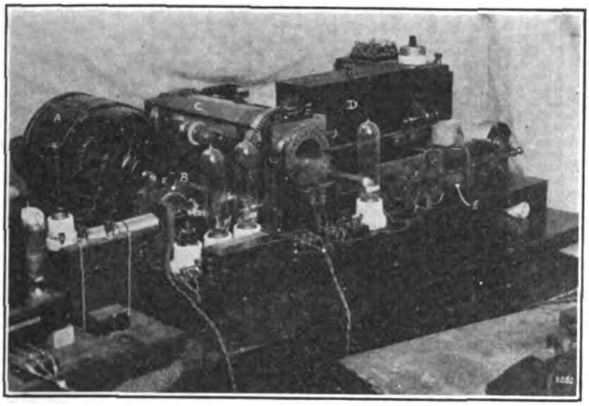

Figure 12—The First Photoradiogram Transmitter, 1924. This Unit is now in London

inside of this cylinder. To give an idea how powerful this light is, a few figures are cited:

The Incandescent Gas Mantel has	35 c.p. per square inch of surface.
The Carbon Filament Lamp has	400 c.p. per square inch of surface.
The Metallic Filament Lamp has	1200 c.p. per square inch of surface.
The Nernst Lamp has	2500 c.p. per square inch of surface.
The Gas Filled Lamp has	12000 c.p. per square inch of surface.
The Gas Arc has	15000 c.p. per square inch of surface.
The Sun	900000 c.p. per square inch of surface.

Naturally it has been one of our main problems to find the very best materials available for each and every part of the system. This has been made easy by the ready reception we have received from everyone, such as lamp manufacturers, ink manufacturers, fountain pen, paper, camera suppliers, etc., and others affiliated in this work. May I state what a pleasure it has been to have had such a wealth of material offered us in this work.

10. Revolving Cylinder

This strong gas arc-light is in the inside of the glass cylinder and sends its ray by lenses through the film placed on the cylinder to a motion picture lens focused on the film which throws an image of the film onto the photo-cell, point by point. As the cylinder

revolves, each portion of the picture is shown progressively to the photo-cell. The photo-cell is then moved bodily down the cylinder length so that the whole picture is gradually built up line upon line.

Figure 13 is a view of the commercial type of transmitter of the present time.

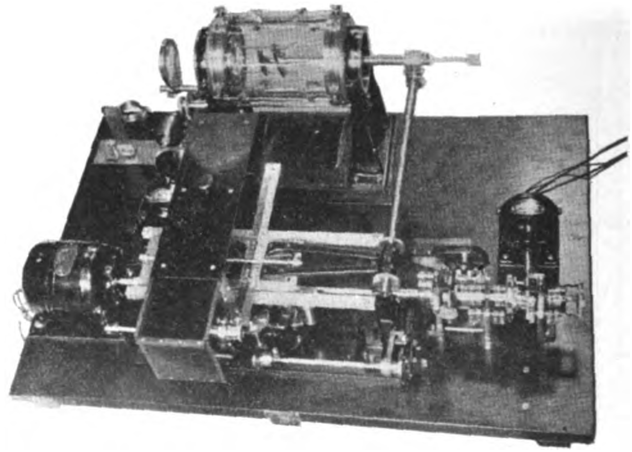

FIGURE 13—The First Commercial Type of Photoradiogram Transmitter, 1925

11. PHOTO CELL

In the camera box (Figure 14) is the electric eye, the photo-cell, which is a device for interpreting light values in terms of electric current. I believe it was Shelford Bidwell who first suggested the use of light sensitive electric valves for photo transmission work. Many others since then have contributed to this plan, notably, Elster and Geiter in Europe. We are indebted to the General Electric Company and to the Westinghouse Company for the excellent photo-cells they have developed for us in this work. Basically, the idea of the photo-cell is that a high voltage is applied to the cell, almost sufficient to ionize it. Photo-electric action is realized when light strikes a photo-cell such that the potassium hydride which lines the inside surface of the cell is ionized and electrons pass from the potassium hydride to the cathode in the center of the cell. Highly attenuated argon gas fills the inside of the cell which increased the ionizing effect materially, so that an appreciable current flows through the cell with the action of the light to the extent of some two micro-amperes. This current, of course, must be greatly amplified,

which is done by the use of the three-electrode vacuum tube. This is shown on the attached circuit, Figure 15, where the current is caused to pass through a high resistance, R, which causes voltage variations to be applied to the grid of the vacuum tube. This amplification might be carried on in further steps in the usual manner. However, for our first dot concentration plan this was quite sufficient in itself to give effective results. This is

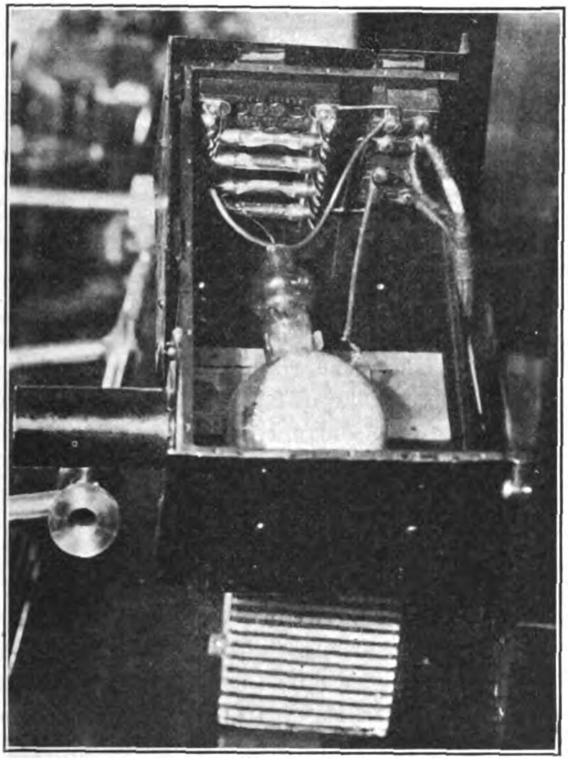

FIGURE 14—This View Shows the Photo-cell in the Photo-cell Box

arranged by having a vacuum tube with its grid thus controlled by the photo-cell, with its plate current supplied through a condenser charged at intervals. These intervals are determined by the rate at which the condenser discharges. In other words, a sort of low-pressure valve is arranged such that when the condenser discharges to a certain extent, the plate battery is again connected to the condenser to charge it up to the maximum value. This is accomplished by having a large C battery connected to the high side of the condenser so biased that the plate voltage

must fall below a given value before a second three-electrode tube stops drawing plate current through its plate. This second plate current is carried through a relay; while the relay coil is energized the contacts are open, but when the relay falls back against the contacts the charging *B* battery pulse is sent on to the condenser.

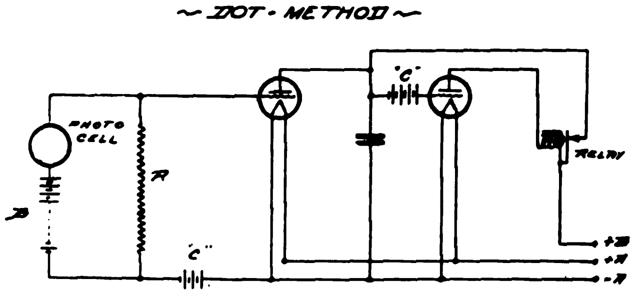

FIGURE 15

It is thus seen that the time interval between the successive charges of the condenser is determined by the rate of the plate-current flow in the first vacuum tube, and as this is in turn determined by the photo-cell current, we have a direct interpretation of the light action in terms of the relay closing. This relay closing can be used to activate telegraph lines or a telegraph radio circuit.

12. *C* LIGHT

As an interesting adjunct to our photo-cell operation we may mention the use of an additional light beyond the normal illumination obtained through the film to be transmitted; this we have termed the *C* light, Figure 16, corresponding in its action very much to the *C* battery used in grid amplification. The use of the *C* light makes it possible to operate the photo-cell itself more effectively, where it, in conjunction with the amplifiers, gives a more perfect straight line characteristic to the reproduction current values.

13. SYNCHRONISM

For synchronizing, we have adopted the tuning fork as giving us the appropriate constant rate of rotation to actuate our devices both at transmitter and receiver. By the addition of clock check control we have found it possible to obtain uniform speeds at each end, where the clock controls act as a check on the tuning fork. Aside from using clock control we have also used dashes

at the end of each stroke, which work very well to keep the receiving cylinder moving correctly with respect to the transmitting cylinder.

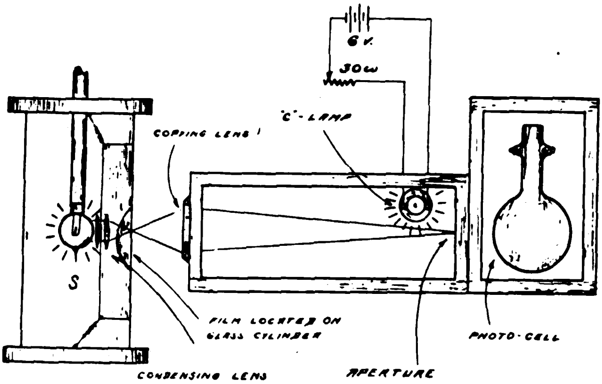

FIGURE 16

14. The Receiver

For the receiver there are many available plans, but we have concentrated on the production of a daylight operation program which involves the use of something in the order of an ink record on paper. It is seen that this dot plan fits in very readily with an ink record. It is only necessary to have the recording pen mark on the paper whenever a charging pulse starts at the transmitter. The connection between the transmitter and receiver may be either by telegraph or by the regular radio telegraph.

Figure 17 is a close-up of the original receiver with most of the auxiliary apparatus excluded. *A* is the motor which is maintained at constant speed through the medium of the tuning fork *G* and associated apparatus. *B* is the reversing cam for changing the direction of rotation of the drum *C* upon which the recording paper is placed. *D* is the pen which is supplied with ink from the well, *E* for reproducing the picture as it is received, in the form of dots and dashes. *F* is the box for the film by means of which it is possible to obtain a photographic record at the same time the visible record is being made.

Figure 18 shows the modern type of photoradiogram receiver which is capable of making two pictures at the same time.

15. Static

The question of transmission to a distance is always one of obtaining sufficient desired signal strength to override the effects

of disturbances. This is true of all wire lines and cables, as well as radio. It is in this element that the telegraph wins, due to the fact that it is in a sense a trigger device, where the current is either on completely or off completely. Under these conditions

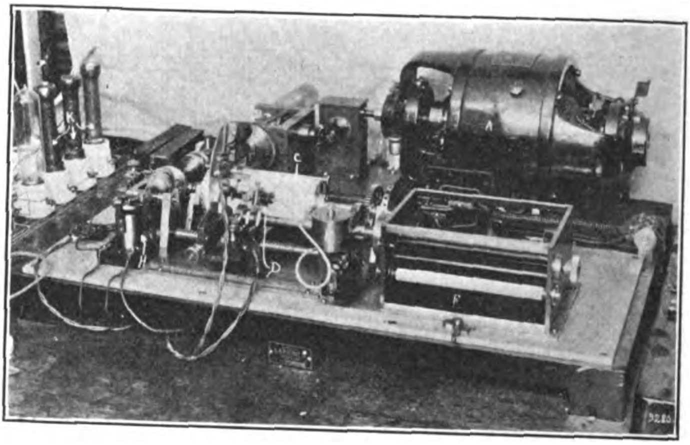

FIGURE 17—The First Photoradiogram Receiver which is still in the Design Laboratory of the Radio Corporation of America in New York, 1924

it becomes easier to identify electro-mechanically the times when the current is on and when it is off, than to attempt to analyze the variations in current strength. That is why it is

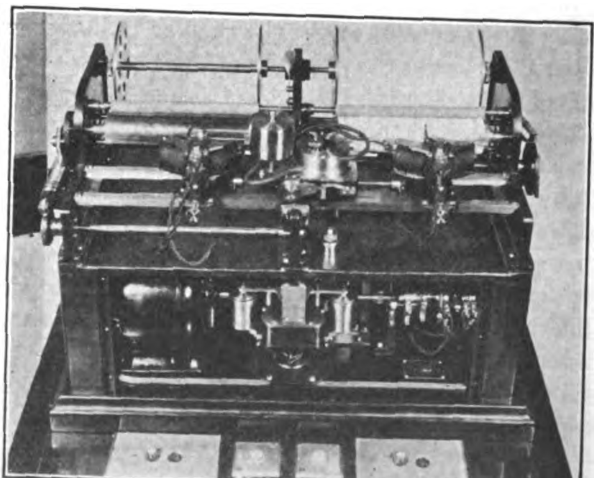

FIGURE 18—First Commercial Type of Photoradiogram Receiver, 1925

possible to get radio telegraph signals across the ocean at practically all times whereas even considering the smaller amount of power used, I am sure it is appreciated that broadcast telephony, for example, is badly interrupted by static and fading over much shorter distances. By interpreting picture values in dots and dashes, where the full current of the radio transmitter is on even for the shortest dot, we have taken full advantage of this telegraphic supremacy to carry a picture to the greatest distance. Furthermore, it fits in most readily with the relaying operation. This we first made use of on July 6th of last year when the following picture of Secretary Hughes, Figure 19, was sent from New York by wire line to New Brunswick, N. J., thence by radio to Brentwood, England, then into London and from there by wire line back to Carnarvon, Wales, thence back by radio to Riverhead, L. I., and back into New York City. This picture

FIGURE 19—First Photoradiogram, New York to London, Back to New York, July 6, 1924

is the result of this very involved journey. No picture was recorded in England, but it showed the effectiveness of our system at that time, so that when the apparatus for transmitting was sent to London the very first pictures came through successfully.

16. Some Early Photoradiograms

The first public trans-Atlantic demonstration of the transmission and reception of pictures by radio took place in November,

1924. The photoradiogram transmitter was located in London. The signals from this apparatus were put on the 220-mile land line to Carnarvon, Wales, at which point they actuated the control relays of the high power radio transmitter there. These radio signals from Carnarvon were picked up at Riverhead, Long Island, amplified, heterodyned, detected and sent in to the New York office of the Radio Corporation of America as audio frequency dots and dashes. These tone signals were again amplified at the New York office, then rectified and applied to the photoradiogram receiving equipment.

In the spring of the following year (1925) a photoradiogram transmitter was installed in the offices of the Radio Corporation of America at Honolulu. On April 29th, 1925, pictures were successfully transmitted from Honolulu and reproduced in the New York office of the Radio Corporation of America.

17. Commercial Uses

Naturally, all this work has a purpose in view, and, of course the news field is the most immediate. There are two angles, however, to the newspaper situation: first, is the unusual picture, and the other is the general news picture. Naturally, a business can not be built up around earthquakes. Therefore, it must be a case of supplying regular service to groups of papers that this service will become worthwhile. However, it is interesting to see to what extent the unusual picture will force news activities. I have received the following advice as to two particular instances of the unusual picture situation:

Some examples of the need for radio pictures are to be derived from news events of the past year. The earthquake in Japan was the cause of one of the greatest races between news-gathering agencies in modern times. The representative of one agency had flown from a Chinese port over the stricken area, taken several desirable photographs, and then returned in time to mail his results on a Pacific Mail steamer sailing from Shanghai. His competitor had been forced to make the trip to Japan by both air and water and arrived some twenty-four hours after the steamer had sailed. Chartering a seaplane he made a dangerous four-hundred-mile trip to sea in order to drop his package of film on the ship. Successful in this, the race was tied until Vancouver was reached, where two speedy planes awaited the ship's arrival. From there, across the continent it was a free-for-all race, one leading and now the other. Eventually, the pictures were delivered in New York with but a few hours' difference in time. Had a radio picture service been available, but a few hours would have transpired instead of the many days to transport the scenes of this disaster. The cost ran up into

thousands of dollars and many New York papers paid as high as five hundred dollars for pictures weeks old.

One picture-gathering agency sent a representative around the world with the Army fliers. Traveling in many different ways and even stowing himself away on one of the the planes, he was handicapped in keeping his service supplied with pictures from three to six weeks old. With a world-wide radio picture service it would have been but a matter of hours. With the public desire for pictorial news becoming more pronounced yearly, it is only natural that a demand for foreign pictures with foreign news items be met through radio pictures.

A very effective use to which photoradiograms will be put is distinctly in line with the original work of Alexander Bain, as emphasized in our particular development by Mr. Young, and that is, transmission of words—printed, typewritten or hand written. As an example of printed material may be mentioned a clipping taken from a Honolulu newspaper and transmitted all the way to New York by relay through California, in May, 1925. Tabulated material is particularly suited to such transmission and most difficult to accomplish by normal telegraphy. Drawings, signatures, fingerprints, and all such are a fruitful field for radio pictures.

Naturally, there remain many refinements necessary in this work, but it is largely a question of making the equipment continuously serviceable. To this end we have made both transmitter and receiver such that the operations may be continued without interruption between pictures, and with the equipment now set up and working both eastward across the Atlantic and westward to California and Honolulu, it is only a question of time when the mechanics of the operations will have been sufficiently worked out by the operators, who have to combine all that went before, in a way of radio technique with mechanical and artistic appreciation as well, to make photoradiograms of the highest service to everyone.

SUMMARY: This paper carries the art of electric picture transmission from its inception, over 80 years ago, to the results of present-day development.

It is pointed out that the seemingly rapid strides that have been made in the art during the last 10 years of its 83-year existence may be attributed to the larger storehouse of electrical and mechanical contrivances from which modern photo-transmission engineers may draw.

Picture transmission is not, as many think, a modern art. It is as old as the communication art itself and this paper carries us through the work, ancient and modern, of photo-transmission engineers, commencing with that of Alexander Bain in 1842.

A Denison facsimile of telegraph tape, taken in 1901, is shown, together with examples of the work of Korn taken in 1922; that of Bart-Lane in 1922; Belin, 1924; Ferree, 1924; Jenkins, 1924; and results of the A. T. & T. system in 1925.

The basic elements of all picture transmission systems are shown to consist of synchronously covering a surface, point-by-point, at both transmitter and receiver, and electrically identifying point values at the receiver so that any integral section of the received copy will have the same relative tonal value as the identical integral section on the transmitting surface.

Economics is as important a factor in the transmission of pictures as it was in the establishment of a telegraphic system of communication, and the reason that the Morse Code still exists is because it is the most economical means of getting a given amount of words from one point to another, in the shortest time, with the least power, over the greatest distance and through the greatest amount of interference.

The necessity of a picture shorthand was visualized and developed. Whereas the usual newspaper half-tone has 65 dots to the inch and 5 tonal values are desired per dot, making a total of 325 photo-pulses per inch, the picture shorthand developed in the "photoradiogram" system reduced this to 65 photo-pulses per inch giving a reduction or shorthand ratio of 5 to 1.

The photographic angle of the problem is touched on lightly and the 11,000,000-mile-a-minute flight of the picture pulses from the transmitter to the receiver are followed through their several transformations in "slow-motion."

The development of this system of picture transmission is shown graphically by examples of photoradiograms taken from epochal stages in the course of the development.

The commercial possibilities of this system are discussed, and in closing it is pointed out that one very immediate and effective use to which photoradiograms will be put is in the transmission of words, printed, typewritten or handwritten.

SLEET REMOVAL FROM ANTENNAS*

By

J. H. Shannon

(Radio Corporation of America, New York)

The phenomenon of sleet forming on wires, which are exposed to the weather when the temperature is about freezing point and the atmosphere moist, is well known. It is a source of extreme annoyance to a great number of commercial enterprises, more particularly to power companies, in respect to their transmission lines; telegraph and telephone companies in regard to their overhead wire system; and radio companies in connection with their antenna systems.

With regard to the first two industries, the wire systems are so extensive that with the exception of one or two of the power companies, sleet melting is not resorted to; consequently interruptions, due to wires breaking, and towers and poles uprooting as a result of the heavy ice load, are frequent in districts where sleet is prevalent. Large sums of money are expended annually by these companies for maintenance and repair, as well as penalties for interruption to service of customers.

Fortunately for radio companies, the antenna systems are not so very extensive, and when sleet forms on the wires it is possible to pass a current of electricity thru the wires, thus raising their temperature to a point where the ice will melt and fall off, and in case the power supply at the station fails and it is impossible to melt the ice from the wires, a method of automatically dropping the wires when they have been loaded to a predetermined value has been devised. The method of melting ice and dropping the wires will be described.

If the antenna consisted of two wires, these wires being approximately two miles long and supported by means of insulators from towers spaced say twelve hundred feet apart, then it would be a simple matter to melt the sleet from these wires by connecting the far ends permanently together and applying a voltage across the wires at the station end.

The voltage can be so chosen that a current of the desired amount can be passed thru the circuit and thus insure that the wire will not be heated to such a temperature that the strength of the wire will be affected.

*Received by the Editor, June 6, 1925. Presented before The Institute of Radio Engineers, New York, September 2, 1925.

An antenna system is not usually as simple as this and may consist of anywhere from 12 wires up to 30 wires, each two miles in length, all of these wires being connected at a minimum of five points thru inductance coils to the ground, as represented diagrammatically in Figure 1. If we connect the wires together at

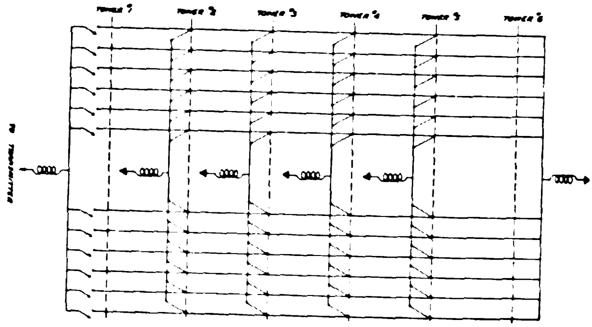

FIGURE 1—Schematic Wiring Diagram of Multiple Tuned Antenna.

the far end we have the same arrangement as our simple two-wire antenna before mentioned except that we have introduced several ground connections to each one of these wires. It can be seen that unless these ground connections are removed in some way we could not effectively pass current thru the whole length of the wires for sleet melting, and it would indeed be a difficult and inconvenient thing to disconnect each of the wires at the ground points when it is required to melt sleet. This, however, can be avoided by the insertion of a condenser between the wire and the ground connection (see Figure 2), this condenser being so designed that it offers a very high impedance path to the low-frequency sleet-melting current, allowing practically none of it to pass thru to ground, whilst offering very low impedance to the high frequency energy, allowing practically all of it to pass thru the coils to ground.

The mechanical and electrical design of a suitable condenser for this purpose was one which presented difficulties and required careful development. It was recognized that the best place for such a condenser to be installed was as close as possible to the point where the tap was made to the horizontal antenna wire at the suspension point, so that it would not be necessary to insulate the down lead wires from each other. Consequently a condenser which could be suspended aloft and carry the main horizontal antenna wire appeared to be the best solution, and such a

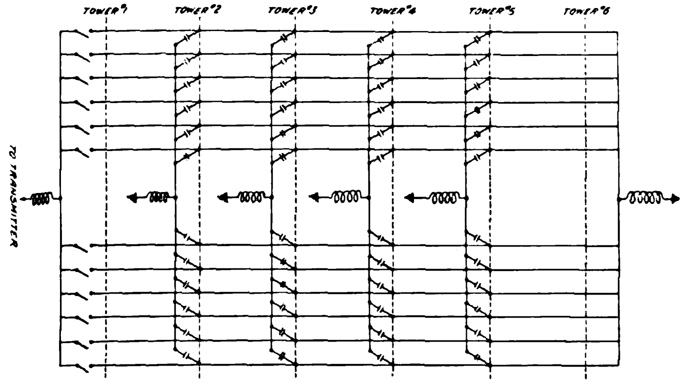

FIGURE 2—Schematic Wiring Diagram of Multiple Tuned Antenna Showing Where Condensers Are Inserted for Sleet-Melting Purposes

condenser was finally developed in co-operation with the General Electric Company at their West Lynn Works.

The plates of this condenser consist of aluminum foil and the dielectric consisted of waxed paper. The assembled condenser element is circular in form, being rolled on a brass mandrel.

The mandrel has an insulated coupling in the centre so that by attaching the plates to each end of the mandrel by suitable clamps, the ends can be used as the terminals of the condenser.

This condenser in its present form lends itself very readily for general use indoors, and with slight modifications could very conveniently be used for power factor correction, and similar purposes, as it can be mounted by simply clamping it between buses without any complicated mountings.

To make it serviceable for outdoor use, as we required, it was necessary to put some form of housing around it. If a metal housing had been adopted, trouble would have been experienced with insulating bushings, and other complications, so a hollow porcelain tube insulator, fitted with end caps and suspension lugs, was finally decided upon as the most practical solution. It was with the co-operation of the Locke Insulator Company, of Victor, New York, that this insulator was developed and produced.

The porcelain insulator as designed for this purpose is shown in Figure 3. One cap is permanently cemented to the insulator whilst the other cap is made in two parts; one part is in the form of a ring and threaded with a male thread, this part being permanently cemented to the other end of the tube. The other parts, or cap proper, with a female thread which can be unscrewed so as to allow for assembly of the condenser element. Should the condenser at any time break down, it is a simple mat-

ter to unscrew the cap, take out the element, and replace it.

By referring to Figure 3 it will be observed that the ends of the mandrel have been extended and threaded. One end is screwed down into the permanent insulator cap, whilst the other end makes contact with the other cap by means of a diaphragm plate, this plate being attached to the end of the mandrel by two nuts. The plates serve two purposes: (1st) for the electrical connection to the cap, and (2nd) to allow for longitudinal expansion of the mandrel due to temperature change.

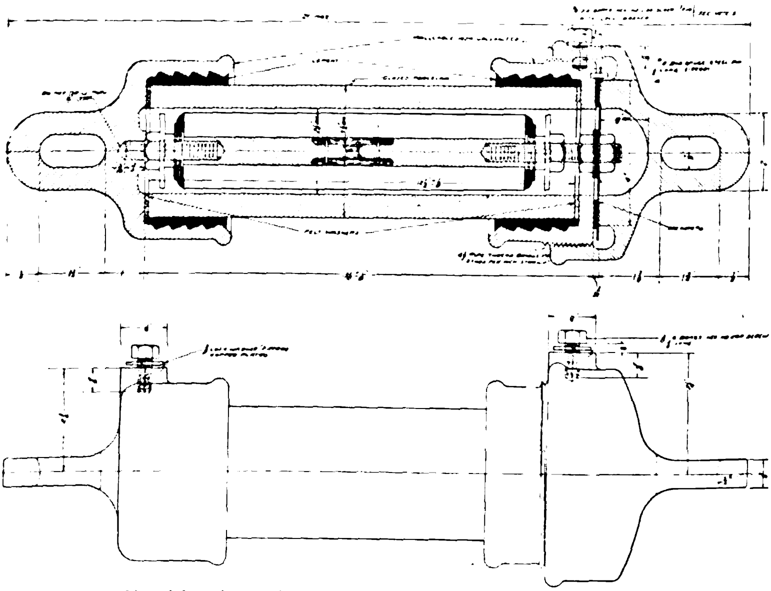

FIGURE 3—Combination of Condenser and Insulator for Sleet-Melting Purposes

The caps of the insulator now form the terminals of the condenser as well as acting as heat radiators for the unit. A special boss on the caps, finished with a flat surface and fitted with a ⅜-inch set screw and lock washer, forms the connection for copper connecting lugs.

The complete unit shown in Figure 4 makes a very neat arrangement, from a mechanical as well as electrical standpoint, as it can be suspended from the main antenna insulators and the antenna cable can in turn be suspended from the lower end of the condenser unit. The antenna wire can be connected to the lower cap and the top cap being connected to a common bus, the down-lead connection to the tuning coils which are erected on the ground, being taken from this bus. So long as power is available

and these condensers are in circuit, no danger from sleet need be feared.

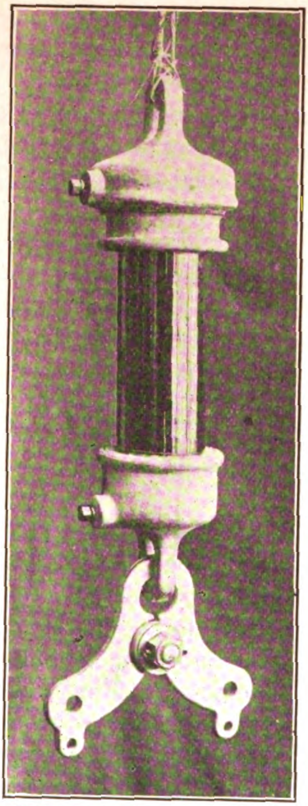

FIGURE 4—Condenser-Insulator Unit with Plyotrip Release Link

Unfortunately, as before stated, very few power companies are able to melt sleet from their transmission lines, and consequently their lines fail, due to wire breaks and uprooting of poles, thus cutting off the power supply to the radio station. Under such conditions it is to be expected that the antenna system will be crippled.

Where self-supporting towers with cross-arms are used for the suspension of the antenna cables, it would be a very serious problem if three or four of the outer wires broke in one span and the others remained intact. Under such conditions a big unbalanced torsional pull would act on the cross-arm, due to the ice and wind load, and unless the design of the tower was made to resist it, results would be disastrous. It would indeed have been very

uneconomical to have designed towers to withstand such conditions unless very low-breaking strength cables were used, but as this would have introduced many disadvantages, foremost among which would have been frequent interruptions to service, it was not practical to adopt such a method.

It was finally decided to install a cable that would have a high ultimate strength, in other words, a cable that would not break except under exceptional conditions. Then interruptions would be reduced to a minimum.

The use of a stranded medium-hard-drawn-copper or silicon bronze cable to give a high ultimate strength would not have been economically satisfactory, as the weight per foot of this cable would have been such as to make the sag on a twelve hundred and fifty foot span (this span having been adopted as it was considered the most economical) so great that the effective height of the antenna would have been low, thus reducing the radiating efficiency of the system, and again, the cost of such cable would have been very high.

The most nearly ideal cable for our purpose was one which had a diameter just large enough so that it did not show corona at 150 kilovolts of radio frequency; of maximum strength possible, and with a conductivity of 35 to 40 percent of pure copper. A cable which satisfied the foregoing characteristics was obtained from the Copperweld Company, of Rankin, Pennsylvania. This cable consisted of seven number-eight wires, formed into a strand of $\frac{3}{8}$-inch diameter. Each wire had an exterior coating of pure copper with a high tensile strength steel core. The ultimate strength of this strand was 12,500 pounds and the yield point considerably in excess of 80 percent of this value. By the adoption of this cable the biggest percentage of trouble due to sleet was automatically eliminated.

In order to protect the towers against abnormal conditions which would exist if the power failed and sleet continued to form, it was necessary to devise some means by which the strain on the towers could be relieved before it got to dangerous proportions. The first thing that suggested itself was a weak link from which the antenna cables would be suspended, this link to break and allow the wires to drop at a predetermined load. This link is shown in Figure 5. By varying the cross section of metal in the link it can be made to break at any desired load. The specifications for this link were somewhat severe and it was indeed difficult to obtain a metal that would fulfil them in all respects. Amongst other things the specifications for this link called for

(1) The elastic limit to be at least 90% of the ultimate strength.

(2) Must be rust proof.

(3) Must not crystallize.

(4) Must break within 3% of estimated load.

After a number of experiments John A. Roebling Sons and Company produced a link, Figure 6, built up of straight pieces of wire, which proved very satisfactory. By varying the number of wires the strength can be adjusted to any desired amount. These links were installed on one of our stations and have been in service for over a year, but so far they have not been called upon to demonstrate their efficiency in case of emergency.

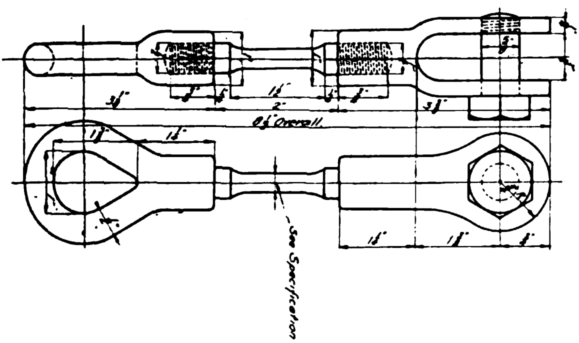

FIGURE 5—All-Metal Weak Link for Antenna Wire Suspension. (Allows Wire to Fall When Overloaded)

Whilst this link has proven satisfactory, it was thought that a mechanical device would be more convenient. A device that will relieve the strain at a pre-determined value and allow the antenna cable to drop for its whole length has been perfected. This device does away with the expense of renewals incurred by a breakable link, as it can be readjusted and put back into service after it has operated.

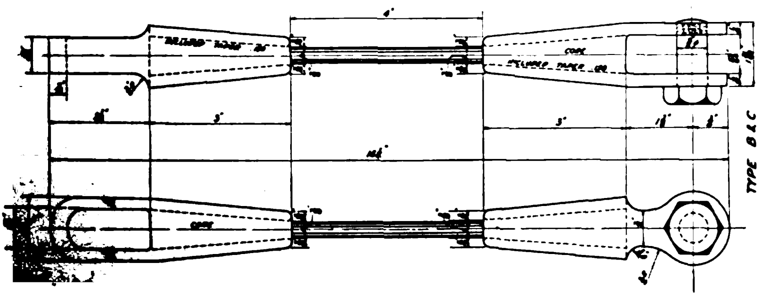

FIGURE 6—Weak Link Made Up of Straight Pieces of Wire for Antenna Wire Suspension. (Allows Wire to Fall When Overloaded)

The device is shown in Figure 7. It consists of a dynamometer spring X fitted with two jaws A and B. The jaw A is fixed whilst the jaw B is free to open. Attached to the end of the jaw B is a trigger C. An adjustable arm D is attached to the centre of the spring. At one end it is rigidly fastened by a lock nut to the spring at the point E, but can move through a guide F at the other end, the guide being rigidly fixed to the spring. Turned solid with the arm D is a hub G which serves to keep the trigger locked under normal load conditions. As the load comes on, the spring compresses, thus causing the arm, and consequently the hub, to move horizontally to the right. If the tension in the wire exceeds the amount for which the device has been adjusted, the spring will be compressed to such an extent that the hub will clear the trigger, allowing the latter to dissengage

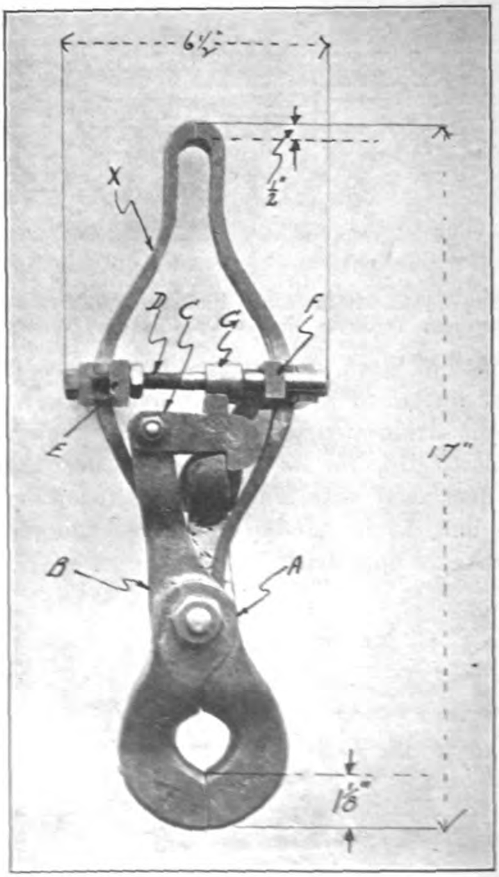

Figure 7—Device for Automatically Releasing Wire When Tension, Due to Sleet, Becomes Too Great.

itself from its locked position and thus allow the jaw B to open and release the cable. (The cable is attached to the device by means of a closed socket.) This automatically allows the cable to come adrift from its anchorage, thus relieving the tension.

For simplicity of description we will call this device the "Dynotrip." This device was developed in cooperation with the Kolbusch Company of Jersey City.

In order to allow the cable to drop from its suspension points on the towers when the tension has been relieved, a plier-like link, as shown in Figure 8, is used. For future reference we will

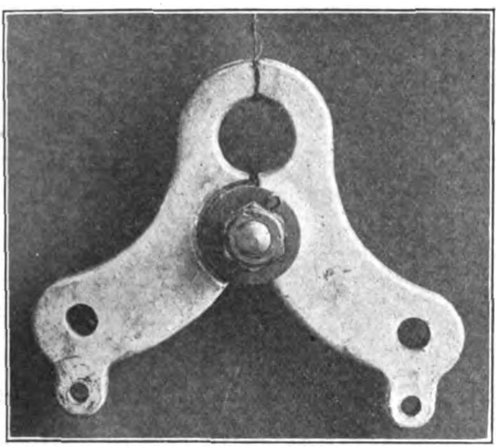

FIGURE 8—Device for Allowing a Wire that Has Been Automatically Released to, Fall from Several Suspension Points

call this link a "plyotrip." The angle of pull-off on this "plyotrip" is such as to keep the jaws tightly closed as long as the cable is in tension. As soon as the tension is relieved, and consequently the angle of pull changed, the jaws open allowing the cable to drop from its suspension points. As one of these "plyotrips" is used at each suspension point, they all release consecutively, allowing the whole cable to drop. In order to install the "plyotrips" it was necessary to have the antenna wires of each span attached to the "plyotrips" by means of open sockets; this broke up the continuity of the wire and introduced a possible source of trouble due to bad contact thru the plyotrip. This, however, was overcome by bridging the plyotrip by means of a piece of flexible braid attached to each socket lug. Also as each antenna wire had to be connected to the condenser to allow the current to pass to a common bus and thence to ground, it was necessary

to connect each antenna wire to the condenser at the point of suspension also. Figure 9 shows the details for the attachment of the antenna wires to the plyotrip and also the electrical connections, which connect the two cable spans together and which connect the cable to the sleet-melting condenser. It also shows the connection from the other terminal of the condenser to the "I" beam buses.

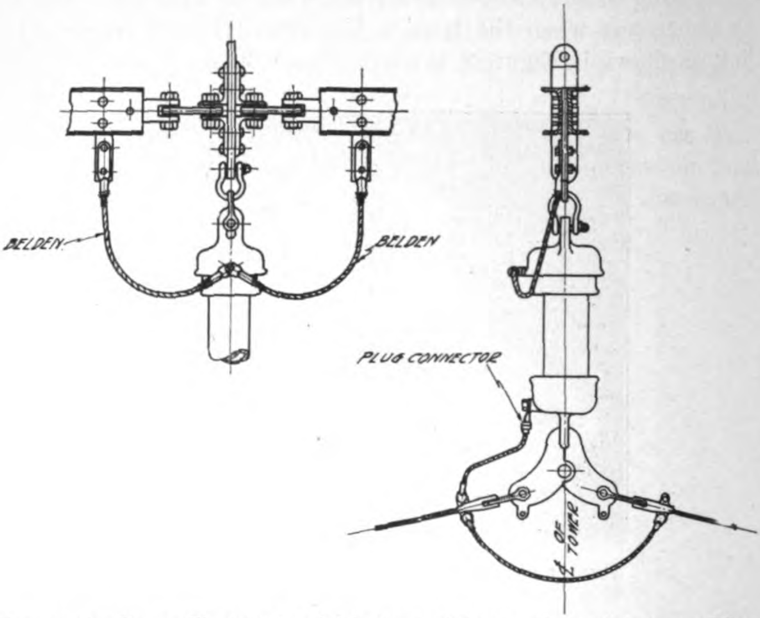

FIGURE 9—Shows Electrical and Mechanical Connections of Antenna Wires to Condenser-Insulator and Bus for Sleet-Melting Antennas.

The terminal which makes the connection to the condenser instead of being a lug is made in the form of a plug connector, shown in Figure 10. When the link releases, this plug pulls out and allows the cable to fall. If it were not for this plug connector it would be possible for the plyotrip to release and the braid connector take the weight, thus preventing the cable from falling. All these electrical connections are made of flexible copper braid and all lugs and terminal plugs are fitted with springs so as to prevent the braid breaking off at the point of attachment to the lugs due to vibration caused by wind.

Figure 11 shows the general assembly of six antenna cables on one-half of the bridge arm, and Figure 12 shows an actual photograph of the installation.

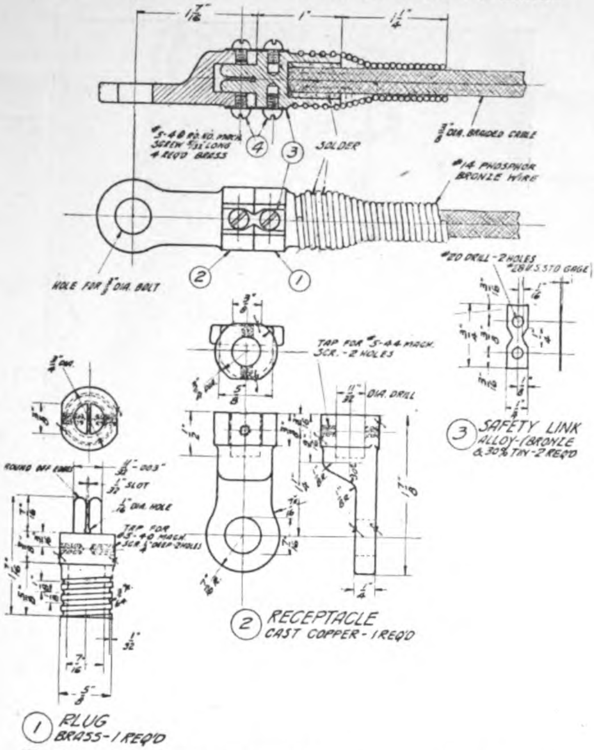

FIGURE 10—Connector which Automatically Comes Apart When Subject to Excessive Tension.

The "I" beams between the insulators form a common bus from which the down lead to the tuning coils is taken. They also act as spreaders for keeping the cables apart.

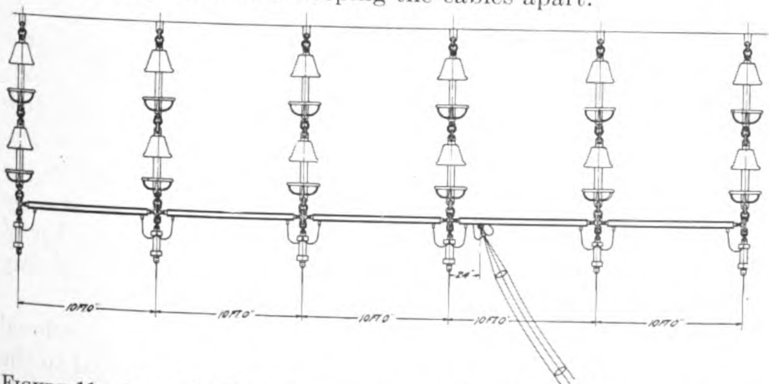

FIGURE 11—Assembly Showing Suspension of Six Horizontal Antenna Wires for One Side of the Cross Arm of a 400-Foot Tower. Antenna Insulators with Rain and Corona Shields, Spreader-Bus, and Sleet-Melting Condensers Are Shown.

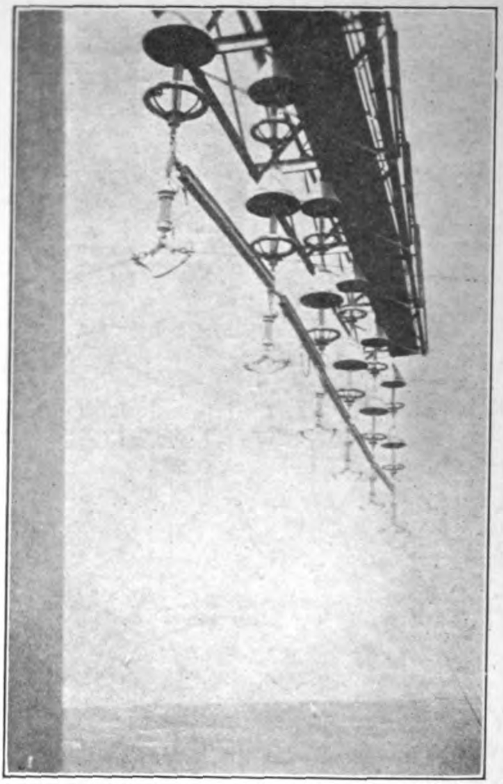

FIGURE 12—Photograph of the Assembly Shown in Figure 11 as Actually Installed.

Figure 13 shows the side elevation of the antenna and the points where the dynotrips and plyotrips are located in the system. It will be observed that the dynotrip is placed in the antenna cable at the far end of the antenna system. This is to facilitate operation. If an antenna cable drops, it is a simple matter to release this cable from its attachment at the power house end; retune the antenna by a variometer which is permanently installed in the antenna circuit to compensate for changes in antenna capacity due to heavy wind, decrease in sag, or reduction in number of wires, and continue operation, the whole procedure taking only a few minutes.

In order to protect the dynotrip from weather, it is enclosed in a canvas bag, a liberal coating of tallow being applied to the dynotrip and to the inside of the bag. This does not affect its operation as the canvas rips open when the "trip" operates.

Sleet melting is done from the 2300-volt, two-phase bus thru

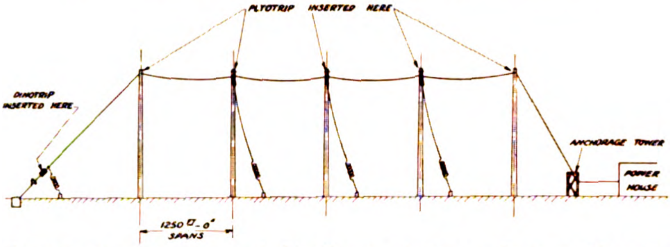

FIGURE 13—Elevation of Six-Tower Antenna System Showing Location of Dynotrip and Plyotrips.

auto-transformers which are used for controlling the voltage. A one-line diagram of the sleet-melting circuit is shown in Figure 15. By means of the push button switch on the control board the transformer switch at the sub-station is closed, putting the auto-transformers directly on the 2300-volt bus. The manually operated O. C. B. in the switch house is then closed, thus energiz-

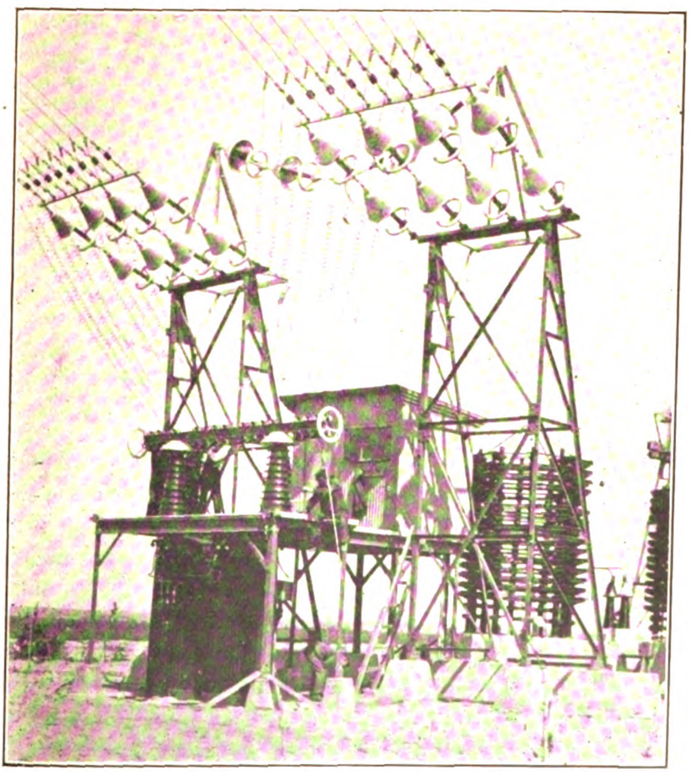

FIGURE 14—Antenna Dead End Structure, Showing Sleet-Melting Platform, Switch Rack, and Sleet-Melting Control House.

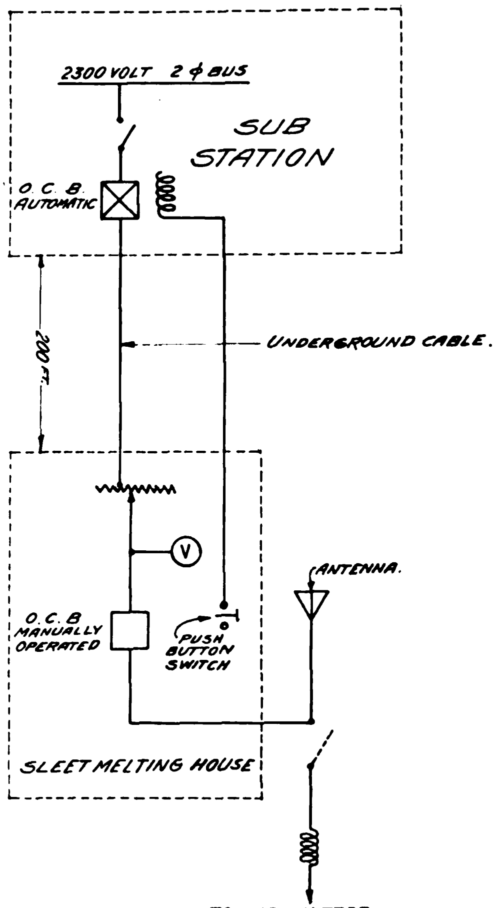

FIGURE 15—Schematic Wiring Diagram of Sleet-Melting Circuit.

ing the antenna wires. The transformer bank of two transformers is rated 500 kilovolt-amperes. They are provided with taps so that the secondary voltage can be varied from 1,000 volts up to 2,200 volts in steps of 200 volts. A total of four wires are melted at each operation. The current required is 300 amperes at 1,600 volts. Figure 14 shows the arrangement of the sleet-melting structure. The two steel towers are the dead-end anchorages for the antenna wires, eight wires being anchored to each tower. The wires are insulated from the towers by four sets of porcelain rods, each set comprising two hollow porcelain insulators, each fitted with rain and corona shields.

The two pedestal insulators on the platform support the sleet-

melting switches which are mounted on an "I" beam. Each wire is connected to a switch by means of a piece of wire formed into a spiral. This is to allow for movement due to wind so that no heavy strain will be put on the switches.

The auto-transformers can be seen underneath the platform. The small house on the platform houses the switching equipment and a telephone. The telephone giving communication to the power house is about 150 feet distant. When it is necessary to melt sleet the switches are opened up and the low frequency cables attached to the antenna side of the switch. One of the field tuning coils referred to earlier can be seen in the background.

It usually takes about five minutes to melt a ¼-inch thickness of sleet from four wires so that on a twelve wire antenna the complete operation takes from twenty to twenty-five minutes from start to finish.

SUMMARY: A method is described for automatically releasing the antenna wires in case of excessive sleet load. Should the wires break under a heavy coating of ice, serious damage to the self-supporting towers would result, due to the unbalanced load. It also describes a new type of suspension condenser developed for the sole purpose of preventing the low frequency energy going to the ground and thus making it possible to melt sleet from the individual antenna wires of the multiple tuned antenna without the use and inconvenience of complicated switching at each ground point. The mechanical as well as the electrical design of this condenser is unique.

Further, it is believed that dynotrips and pliotrips can be adopted to power transmission lines in such a way as to prevent a big percentage of interruptions. These pieces of apparatus can be so arranged as automatically to introduce into the lines at intervals, additional lengths of conductor and thus increase the sag. It is expected that for long spans over canyons, these would be almost indispensable.

RECENT ADVANCES IN MARINE RADIO COMMUNICATION*

By

T. M. Stevens

(Radio Corporation of America)

It is the purpose of this paper to outline, in a brief and non-technical manner, the progress made in Marine Radio Communication during the past few years.

It is not difficult for us to remember that only a short time ago the large passenger ships nearing our shores, or lying at quarantine, caused untold interference to radio telephone broadcasting while transmitting hundreds of radiograms to coastal stations. Indeed, the coastal stations themselves caused interference to almost the same extent in sending radiograms to ships, or in acknowledging those received.

After the termination of the World War, the Naval Communica ran Service, which at that time operated practically all coastal stations in the United States, was severely pressed for competent radio personnel due to demobilization. It was necessary to close many shore stations due to personnel shortage in order to man the fleets, compass stations, and, so far as the Navy was concerned, the more important strategical stations on land.

In the early summer of 1920 one of the larger radio companies found it necessary to establish a system of coastal stations in order to render prompt and efficient public radio telegraphic service. 2-kw. spark transmitters were installed at New York and Cape Cod. Other spark stations were then or about to be placed in service at Cape May, N. J., Babylon, L. I., Brooklyn, New London, Newport, Siasconset, Boston, and Bar Harbor. Shortly afterward, spark stations were established at East Hampton, L. I. and Rockland, Maine. Thus, we see there were no less than 12 spark stations in operation along the coast from Cape May to Bar Harbor. All were operating on only two wave-lengths, viz: 600 and 450 meters. Approximately 90 per cent of the traffic to and from ships was handled on these waves.

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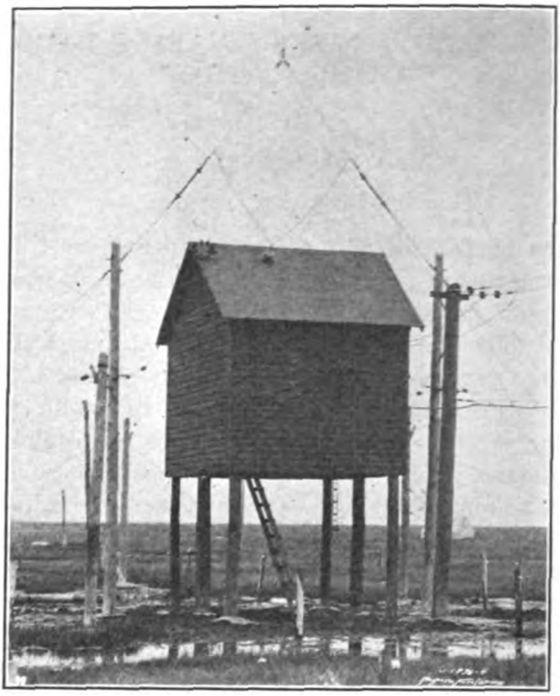
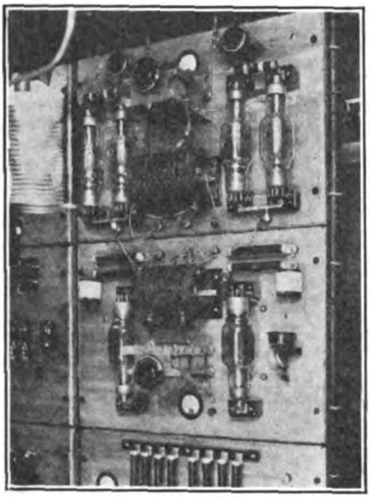
Imagine the interference to the marine radio telegraph service caused by so many stations.



Tuning House at End of Transmission Line, Located 1,400 Feet from the Transmitter in Power House, Tuckerton, N. J.

About this time broadcasting came to us. Fortunate, indeed, was it that vacuum tube radio telegraph transmitters made their appearance simultaneously. The first vacuum tube transmitter for commercial telegraph use in the United States was installed at Marion, Mass. (WCC). It was operated on 2,200 meters, distantly controlled from the receiving station at Chatham. A few of the transatlantic passenger vessels were by this time equipped with either arc or tube transmitting attachments. The shipboard operators, as well as those at Chatham, were astounded at the remarkable distances covered with the tube sets. The larger ships began to use the long wave channel almost exclusively for their traffic, and it became necessary to provide additional channels at the Chatham station. The shipboard transmitter could be quickly shifted from 2,100 meters (the

usual calling wave used by ships) to 2,000, 1,900, 1,800 meters, etc. Thus, Chatham could receive from three ships and transmit to a fourth vessel at one and the same time.



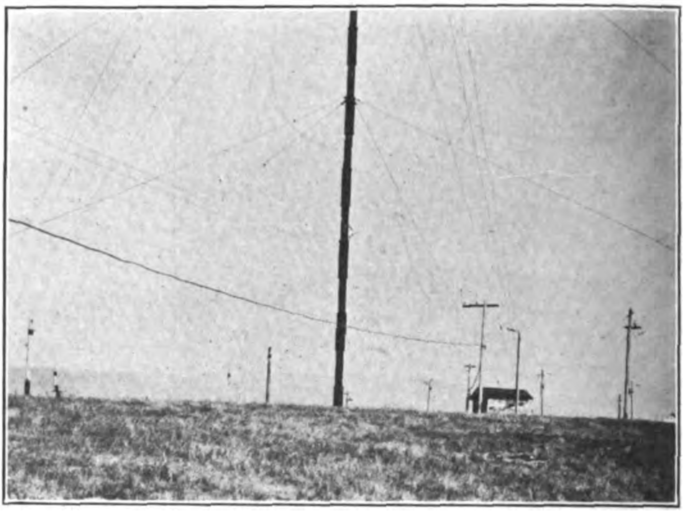
Master Oscillator and Intermediate Amplifier—Short Wave CW Set, San Francisco, Cal.

The use of CW vacuum tube transmitters not only increased the range of marine communication, but greatly facilitated the movement of traffic due to the possibilities of multiplex operation, and, by the removal of heavy loads from the shorter wave-lengths, aided the smaller ships in moving their traffic.

The increased range also resulted in making unnecessary the further operation of numerous stations along the Atlantic Coast. The Bar Harbor station practically ceased commercial activities; stations at Rockland, Me., Newport, Siasconset, New London, Babylon, and Cape May were closed.

As the radio broadcasting activities rapidly expanded, the elimination of spark stations on land was pushed with all possible speed. The Bush Terminal 5-kw spark gave way to a tube transmitter. To the Chatham station were added two 5-kw long wave transmitters and two short wave sets. The Tuckerton station, replacing Cape May, used a 5-kw transmitter. A 1-kw set replaced the 5-kw spark at Boston. The same type of set replaced spark equipment at Galveston. Apparatus similar to that at Chatham replaced spark sets at San Francisco, and a special CW set was installed at Los Angeles. The Chicago

coastal station has tube equipment similar to that at Galveston and New York. The company with which the writer is connected has no spark equipment in use at its coastal stations.

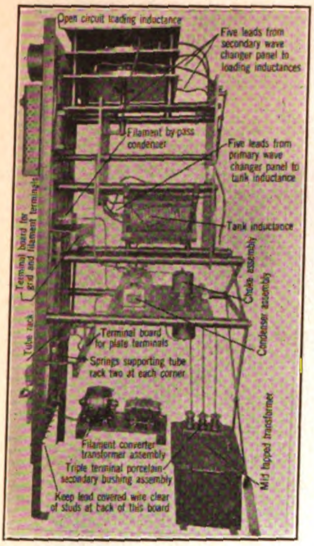


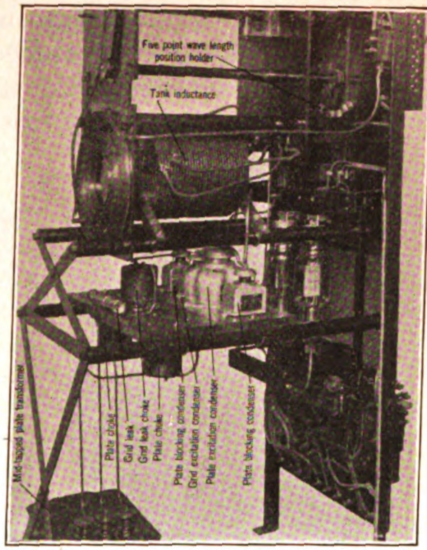
Tuning House and Transmission Line, San Francisco, Cal.

Although the apparatus used for transmitting was developed at the time of the Cape Cod installation, it was found that it suited the purpose without any changes. However, when the demand came to provide similar equipment at other stations, numerous improvements were made in the design tending toward simplicity and efficiency in operation. It was found feasible and advisable to use a power transmission line which made possible the installation of the transmitting apparatus in the main power house of the station, while at the same time erecting the antenna in the most desirable location. In the case of Chatham the antenna is about 800 feet distant from the transmitter. At Tuckerton the antenna and the transmitter are separated by about 1,400 feet. A novel control scheme was worked out whereby the operator at the receiving station could have complete and instant control of the transmitter through the use of only one control wire with ground return. The operator can start the transmitter, change wave-lengths, select CW or ICW signals, and carry on telegraphic transmission, all on this single wire control.

The operation of coastal stations using the vacuum tube type of CW and ICW transmitters does not cause interference to

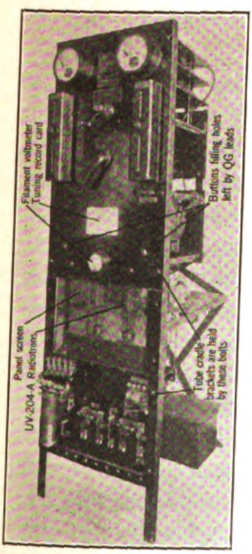
broadcast reception. Therefore, the bulk of the nation's marine communication between ship and shore is now carried on without

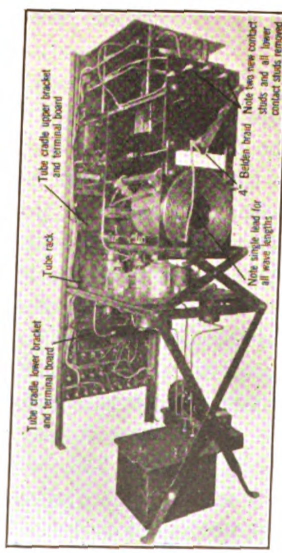




Views of Two-Kw., 500-Cycle Spark Set After Conversion into a Vacuum Tube Transmitter. Right Hand View Shows Condenser and Inductance Arrangement

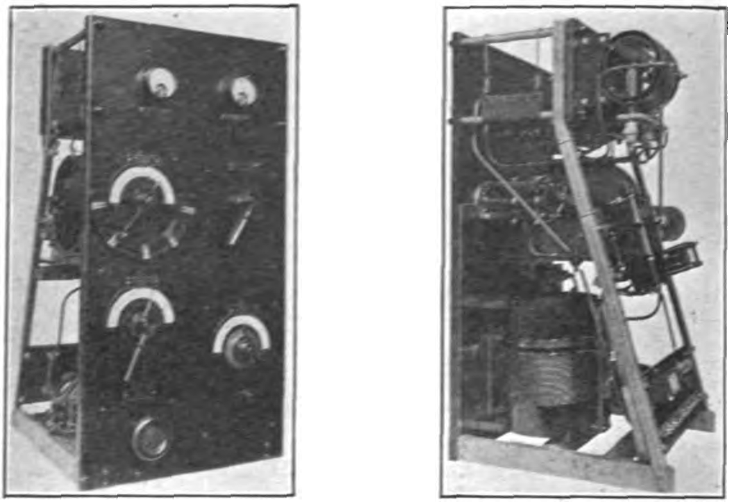
Several hundred sets of this type of transmitter are being converted for shipboard use





Front and Rear Views of 500-Cycle Spark Set After Conversion to a Vacuum Tube Transmitter

disturbing broadcast listeners. European countries are rapidly adopting vacuum tube equipment for coastal stations and a number of countries have sent their engineers and traffic experts to this country to get first-hand information on the type of equipment used in American stations, its general arrangement and operating procedure.



Front and Side Views of 200-Watt CW-ICW Transmitter, Model ET-3627—Wavelength Range 600-960 Meters

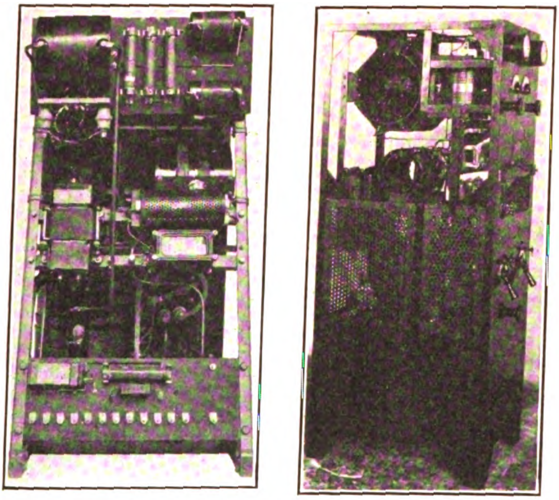
The vacuum tube type of apparatus having proven its superiority in the marine field, is now rapidly replacing sets of the spark type not only on land but aboard ship. Several types of tube transmitters have been designed specially for ship installations, ranging in power from 200 watts in the antenna to 6 kilowatts. A 200-watt set on a ship of average size has a daylight range of from 400 to 600 miles under normal conditions, with a night range of about 1,500 miles. Another type of transmitter delivers 500/750 watts to the antenna, giving a daylight range of at least 1,000 miles under normal circumstances, with much greater range during the hours of darkness.

The 200-watt set is usually adjusted to the following five wave-lengths: 600, 706, 750, 800 and 900 meters. The 750-watt set is usually adjusted to ten wave-lengths, including the five above mentioned and the following five wave-lengths: 1,800, 1,900, 2,000, 2,100, and 2,400 meters.

Radio telephone service is made readily available with appa-

ratus of the newer type through simple addition of a telephone attachment containing necessary modulating tubes, microphones, etc.

Another recent important development makes it possible to convert standard types of spark transmitters into ICW tube transmitters. It has been found that the waves emitted from such a transmitter compare favorably with pure CW. The range of the spark transmitter thus converted is improved practically 100 per cent.



Left: Rear View of 200-Watt CW-ICW Transmitter. Right: Side View of 500/700-Watt CW-ICW Transmitter, Model ET 3626—Wavelength Range 600-2500 Meters

The transmitters on approximately 300 American vessels are being rapidly converted in this manner. This is bound to have a beneficial effect in the elimination of spark interference, as well as in an economic way, for the reason that the spark transmitters now five or six years old are being modernized.

Needless to say, the progress in the reception of signals has kept pace with the developments of the transmitter. Coastal stations have been provided with wave antennas, super-selective and super-sensitive receivers, and with automatic high-speed recording devices.

During the past year, remarkable progress has been made in eliminating spark interference caused by marine radio communication, not only by commercial interests but by the Army, Navy, and Coast Guard.

SUMMARY: It will be seen that the development and use of vacuum tube apparatus by commercial and government stations has not only doubled the range of marine communications, but at the same time has made it possible to carry on a more extensive service with a far smaller number of corresponding stations on shore.

Due to the much sharper waves emitted by vacuum tube transmitters, a greater number of channels have been opened for marine communications, which has resulted in the development of multiplex stations where marine activities are concentrated.

Discontinuance of the use of spark apparatus at coast stations. and to a large extent on shipboard, has almost totally eliminated the interference formerly caused by spark stations.

THE POLARIZATION OF RADIO WAVES*

By

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(Communication from the International Union of Scientific Radio Telegraphy)

In the ordinary practice of radio communication, vertical currents at the transmitter set up vertically plane polarized[1] waves, which are received at distant points on vertical conductors. It has been assumed from the inception of this art that if the wave was vertically plane polarized at its origin, it would remain so at all distances, and the measurements of Austin[2] confirmed this for the low frequencies employed in trans-oceanic working. Later, Smith-Rose and Barfield[3] made similar measurements, extending the frequency range investigated up to 677 kilocycles, and finding, as did Austin at the lower frequencies, that the waves at the receiving point were always substantially vertically plane polarized.

These prior measurements did not cover the upper portion of the frequency band now used in radio communication, and dealt only with waves which were vertically plane polarized at their origin, so that two questions were left unanswered. If the waves left the transmitter vertically polarized, but if the transmission frequency were materially higher than any measured in the past, would they also remain vertical at all distances? And if the waves left the transmitter horizontally polarized, would they remain so at all distances?

The apparatus employed by my predecessors consisted of an ungrounded, linear Hertzian resonator, universally mounted and

*Received by the Editor, October 28, 1925. Presented at the Annual Convention, January 18, 1926, Institute of Radio Engineers, New York;

[1] In this paper the plane of polarization is taken as the direction of electric force in the wave-front; optical terminology is still disfigured by placing these at right-angles.

[2] L. W. Austin. "The Wave-Front Angle in Radio-telegraphy," Washington Acad. Sci., J. II. pp. 101-106, March 4, 1921.

[3] R. L. Smith-Rose and R. H. Barfield. "On the Determination of the Directions of the Forces in Wireless Waves at the Earth's Surface." Roy. Soc. Proc. 107, pp. 587-601, March 2, 1925.

with the receiving apparatus coupled to its center. For the measurements described in this paper, I used the same system, with the addition of a partial ground at the center of the resonator circuit, which not only determined a potential node at this point but made possible a second directional determination.

It must be borne in mind when such measurements are made near the surface of the earth, and a portion or all of the wave under investigation is coming slantingly down upon the receiving point, that some of the wave is reflected by the ground, particularly at the lower frequencies. Therefore, save for slight differential effects, such apparatus gives merely a measure of the resultant electric force from both the incident and the reflected rays. It is, therefore, difficult to determine whether the wave reaches the receiving point along a horizontal or an inclined path, and, equally, it is difficult to determine the true angle of polarization in the incident ray. For example, if an incident wave came down at an angle of 45 degrees, with the electric vector at 30 degrees with the vertical, the resultant observed by the resonator would be a maximum electric force along a true vertical, and a minimum along a horizontal line at right angles with the bearing of the distant transmitter, having an amplitude half that of the vertical. A true determination of the electric forces in the incident ray might be made at very high frequencies over high resistance ground, or, better still, the apparatus could be taken up a kilometer or two by an airship.

For the measurements about to be described, I selected a site on the flats back of Seabrook Beach, New Hampshire, well away from all obstructions, particularly overhead wires, which I assumed would absorb any horizontal component that might be present. Here a wooden tower was erected, and on top of this tower, at a height above ground of seven meters, was mounted a universal joint carrying a linear Hertzian resonator, consisting of a single wire eight meters long. This wire could be freely rotated about both horizontal and vertical axes, and was broken at its center by an insulator, with short leads running to an inductance with parallel connected condenser. The amplifier and observer were also placed near the center of the resonator, to avoid pick-ups other than by the resonator wire. The tower and the dispositions of apparatus on top is shown in Figures 1 and 2.

As with a direction-finding loop, I found it necessary to avoid the disturbing effects of unsymmetrical capacities from the wings of the resonator to surrounding objects, including, of course, the

amplifier and the observer. After some experiment I found a simple means of eliminating these undesired effects, which consisted in connecting the exact center of the resonator system to both the metal support on top of the tower and the filament battery of the amplifier. This is electrically similar to the grounding of the mid-point of a direction finder loop[4] in that it determined a potential node at the center of the system, and greatly sharpened the indications. Another effect of this partial ground was to give the system marked directional properties in a hori-

FIGURE 1

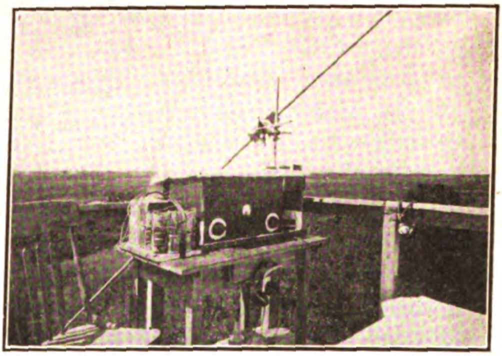

FIGURE 2

zontal plane. Unless the currents flowing to this ground are in phase, which can only be when the wire is parallel to the wave-front, a signal will be produced.

A superheterodyne amplifier, having two stages of intermediate (40 kilocycle) amplification, and one stage of audio frequency following the second detector, was employed in all of the measurements. In addition to the normal superheterodyne oscillator, which operated at input frequency plus or minus 40 kilocycles, a second oscillator was used, coupled into the second detector, and operating at a fixed frequency of 41 kilocycles. This produced an audio frequency beat with any intermediate frequency current which might be produced, and greatly increased the intensity of the signal. The voltage amplification of this receiver, from the grid of the first detector to the grid of the second, was 160, altho the measured amplification of the two intermediate frequency stages was 1,200. This appears to be the normal performance of the superheterodyne, in which a loss of from five to ten-fold occurs in the frequency conversion. The

[4] E. Bellini. "Un Nouveau Radiogoniometer avec Levée du Doute." L'Onde Electrique, No. 29, May, 1923, page 241.

elementary electrical circuit of the Seabrook Analyzer Station is shown in Figure 3.

As most of the stations measured were working in code, galvanometer readings could not be taken, and audibility measurements were used thruout. These readings are very nearly proportional to the squares of the electric fields involved, so that in reducing my observations I simply took the square root of the audibility ratios.

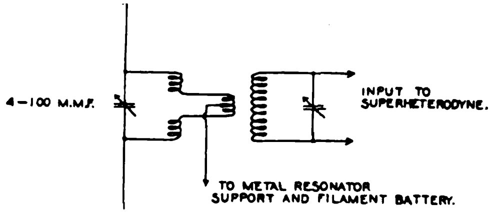

FIGURE 3

In the day time, and for all frequencies under one or two megacycles, the maximum signal was obtained with the resonator vertical. Rotating the resonator about a horizontal axis, the signal decreased, a minimum being obtained when the wire was horizontal. Rotating the now horizontal wire about a vertical axis, the signal passed thru two nulls, 180 degrees apart and with the wire exactly at right angles to the line of propagation. When the wire was set on either of these nulls, a rotation about the horizontal axis of less than one degree, and about the vertical axis of about four degrees, sufficed to bring the signal in again.

In the middle of the day, similar readings were obtained from station 2XK at Schenectady, operating at 2.75 megacycles, altho the null was obtained when the wire was placed in a N-S line, and 24 degrees from the horizontal. Schenectady lies nearly due west from Seabrook, at a distance of 250 kilometers, so this measurement indicates that altho the waves arrived at Seabrook with their front at right angles to the bearing of the transmitter, the electric force was inclined 24 degrees from the vertical. Altho several amateur stations at approximately the same distance and time of day were measured, operating at frequencies from two to four megacycles, no such tilt of the electric force was found, the nulls occurring within a few degrees of the horizontal in all cases; this effect, so far as my observations went, seems to be peculiar to reception from Schenectady.

During the month of August, 1925, and principally in the period from one hour before to two hours after sunset at the

receiving point, over 1,300 measurements of 379 stations were made. Most of these stations were operating on the two amateur bands of 3.5 to 4.0 and 7 to 8 megacycles, and the majority were within a 2,000-kilometer radius of Seabrook, altho a few European stations, and one South African amateur, were picked up and measured. All of these stations (with the exception of some special transmission from Schenectady) were of the antenna-ground or antenna-counterpoise type, operating either at the fundamental or a harmonic, so that the wave left the transmitter vertically plane polarized. In the tabulation following the more important results of this measurement are given.

It will be seen from the following table that the principal factors affecting the ratio of horizontal to vertical electric force are time of day, transmission frequency and distance. For frequencies over about three megacycles, night conditions begin over an hour before receiving point sunset, and altho my data on this point are rather meagre, last until over an hour after sunrise. In the two large groups of amateur stations working in the frequency bands of 3.5-4.0 and 7-8 megacycles, a marked maximum of horizontal force occurs between 200 and 300 kilometers. An ill-defined minimum is then found between 500 and 1,000 kilometers, and following this a slight rise begins. My few measurements of European stations working in these bands gave horizontal-vertical ratios of two and three, respectively.

The amateur stations measured in the United States and Canada subtended at Seabrook an angle of 210 degrees, and if the Cuban and Porto Rican stations are included, an angle of 240 degrees. This gives abundant material for an analysis with respect to direction, that is, with respect to the magnetic meridian. I have made this analysis for the frequency bands of 3.5-4 and 7-8 megacycles, but with entirely negative results; transmission direction with respect to the magnetic meridian does not appear to be a factor determining the ratio of horizontal to vertical electric force.

The answer to the first question is, therefore, that transmission frequencies measured in megacycles do not, like the lower frequencies, arrive at a distant receiving point vertically plane polarized.

A partial answer to the second question came early in 1925, when I found that radiation at 790 kilocycles from an elevated horizontal doublet at Schenectady was received on a symmetrical T antenna and ground at Newton Centre, with approximately the same intensity as if it had proceeded from a conventional

vertical antenna. Measurements made by me in September, 1925, with a more precise apparatus than a T antenna and ground have confirmed this observation, and will be described below.

Station	Place	Distance Kilometers	Time of Day 75th Mer.	Frequency Megacycles	Horizontal Electric Force	Vertical Electric Force	Number of Measurements
WEEI	Boston, Mass.	50	9 A.M.—3 P.M.	0.62	0.0	100.0	3
WEEI	Boston, Mass.	50	5 P.M.—9 P.M.	0.62	1.0	50.0	11
WGY	Schenectady, N. Y.	250	9 A.M.—3 P.M.	0.79	0.0	100.0	5
WGY	Schenectady, N. Y.	250	5 P.M.—9 P.M.	0.79	1.0	30.0	8
WNAC	Boston, Mass.	50	9 A.M.—3 P.M.	1.07	0.0	100.0	10
WNAC	Boston, Mass.	50	5 P.M.—9 P.M.	1.07	1.0	20.0	134
Coast Guard Ships (1)		?	5 P.M.—9 P.M.	2.1	1.0	10.0	7
2XK	Schenectady, N. Y. (2)	250	9 A.M.—3 P.M.	2.75	0.0	100.0	8
2XK	Schenectady, N. Y. (2)	250	5 P.M.—9 P.M.	2.75	1.0	1.1	14
Amateur Stations (3)		30	5 P.M.—9 P.M.	3.5—4.0	1.0	1.3	13
Amateur Stations (3)		62	5 P.M.—9 P.M.	3.5—4.0	2.0	1.0	32
Amateur Stations (3)		90	5 P.M.—9 P.M.	3.5—4.0	2.1	1.0	27
Amateur Stations (3)		154	5 P.M.—9 P.M.	3.5—4.0	2.3	1.0	38
Amateur Stations (3)		205	5 P.M.—9 P.M.	3.5—4.0	2.3	1.0	32
Amateur Stations (3)		290	5 P.M.—9 P.M.	3.5—4.0	2.4	1.0	14
Amateur Stations (3)		350	5 P.M.—9 P.M.	3.5—4.0	1.6	1.0	84
Amateur Stations (3)		542	5 P.M.—9 P.M.	3.5—4.0	1.4	1.0	65
Amateur Stations (3)		1050	5 P.M.—9 P.M.	3.5—4.0	1.5	1.0	12
WBZ	Springfield, Mass. (4)	170	5 P.M.—9 P.M.	3.6	2.7	1.0	13
WIR	New Brunswick, N. J.	450	5 P.M.—9 P.M.	4.1	1.3	1.0	30
WQN	New Brunswick, N. J.	450	5 P.M.—9 P.M.	5.5	1.5	1.0	21
WIZ	New Brunswick, N. J.	450	5 P.M.—9 P.M.	7.0	3.0	1.0	29
Amateur Stations (3)		58	5 P.M.—9 P.M.	7.0—8.0	4.0	1.0	12
Amateur Stations (3)		115	5 P.M.—9 P.M.	7.0—8.0	4.5	1.0	19
Amateur Stations (3)		219	5 P.M.—9 P.M.	7.0—8.0	5.0	1.0	18
Amateur Stations (3)		337	5 P.M.—9 P.M.	7.0—8.0	3.9	1.0	103
Amateur Stations (3)		547	5 P.M.—9 P.M.	7.0—8.0	3.1	1.0	115
Amateur Stations (3)		1000	5 P.M.—9 P.M.	7.0—8.0	1.7	1.0	28
Amateur Stations (3)		1610	5 P.M.—9 P.M.	7.0—8.0	1.8	1.0	35
2XAF	Schenectady, N. Y.	250	5 P.M.—9 P.M.	7.4	3.4	1.0	9
NKF	Washington, D. C.	700	5 P.M.—9 P.M.	7.5	2.4	1.0	7
WBBM	Chicago, Ill. (5)	1300	5 P.M.—9 P.M.	8.0	4.0	1.0	3
WIR	New Brunswick, N. J. (6)	450	5 P.M.—9 P.M.	8.3	4.5	1.0	18
AGA	Nauen, Germany	6400	5 P.M.—9 P.M.	11.5	2.0	1.0	7

(1) Coast Guard stations rarely sign or give position.
(2) Electric vector not vertical, but tilted 24 degrees toward the south.
(3) United States and Canada only.
(4) Third harmonic radiation.
(5) Fifth harmonic radiation.
(6) First harmonic radiation.

On the morning of September 1, 1925, measurements of horizontally polarized radiation were made at the broadcasting frequency of 790 kilocycles. The transmitter was located at Schenectady, and consisted of a horizontal doublet running north 30 degrees west, at an elevation of 90 meters. Tone modulation was impressed upon the carrier wave, and the test covered the period from 12.01 to 1.00 A. M. As measured at Seabrook, with

readings taken every minute, the plane of polarization was predominantly vertical, the average vertical horizontal ratio for the entire period being 10.1. A very considerable variation in the ratio took place from minute to minute, as will be seen from a portion of the log for that period.

Time	Vertical	Horizontal	
12.32 A.M.	10	1	
12.33 A.M.	3	1	
12.34 A.M.	5	1	
12.35 A.M.	10	1	
12.36 A.M.	50	1	Maximum ratio obtained
12.37 A.M.	20	1	
12.38 A.M.	5	1	
12.39 A.M.	2	1	Minimum ratio obtained
12.40 A.M.	5	1	
12.41 A.M.	30	1	

The usual fading occurred during this transmission, but it was very noticeable that at times of low vertical intensity the horizontal component did not decrease in the same proportion; in other words, the amplitude of the fading fluctuations was distinctly less with horizontal than with vertical reception. The tone modulation, however, was less distorted at all times on vertical reception, being distinctly mushy when the resonator wire was horizontal.

With the resonator wire horizontal, rotation around the vertical axis would frequently—every three or four minutes—show nearly absolute nulls 180 degrees apart, and with the wire in a SW-NE line. The maximum horizontal signal was always obtained with the wire in a NW-SE line. As Schenectady is nearly due west from Seabrook, these results show a distortion of wave-front amounting to 45 degrees.

On the evening of September 2, 1925, a similar test was made with Schenectady, using a frequency of 3.75 megacycles. This schedule, which covered the period from 6 to 9 P. M., consisted of alternate ten-minute transmissions from vertical and horizontal doublets, and at Seabrook readings were taken every minute. The horizontal electric vector was found to be over twice as large as the vertical, regardless of whether the transmission was horizontally or vertically polarized. For the entire period, the aver-

age horizontal/vertical ratio for vertical transmission was 2.15:1, while for horizontal radiation the average ratio was 2.16:1; that is, they were substantially identical.

Measurements of static were also made every evening during August, 1925, at several frequencies. In the broadcasting band the static was from 90 to 95 per cent vertical. At three megacycles the vertical/horizontal ratio was about 3:1, while at 7.5 megacycles the vertical and horizontal intensities were nearly equal. A few measurements made at 15 megacycles showed no further increase in the horizontal component.

My findings at Seabrook may be summed up as follows: Under night conditions for frequencies above three megacycles, and for distances over 50 kilometers the electric field at the receiving point is predominantly horizontal. The ratio of the horizontal to the vertical electrical component is determined solely by the transmission frequency and the distance, and is independent of both the direction of transmission and whether the wave left the transmitter horizontally or vertically polarized.

For frequencies above three megacycles, there is a real advantage in horizontal reception. Not only is the electric field and hence the signal stronger, but the signal/stray ratio is markedly improved, because the horizontal component of the static does not increase so rapidly with frequency as does that of the signal. The advantage of horizontal reception is greatest for code working; for radiophone reception the increased audio frequency fading distortion partially offsets the gain in signal/stray ratio.

SUMMARY: Prior measurements of wave polarization made at the lower transmission frequencies have uniformly shown vertical electric force at all distances from the transmitter. The present work extends such measurements to the higher frequencies, where it was found that the electric force at any considerable distance from the transmitter was no longer vertical, but, instead, predominantly horizontal. Comparative measurements were also made of radiation alternately horizontally and vertically polarized at the source, which indicated that the ratio of horizontal to vertical electric field depended only upon the frequency, distance and time of day, being substantially independent of the plane of polarization at the transmitter.

A METHOD OF CALIBRATING A LOW-FREQUENCY GENERATOR WITH A ONE-FREQUENCY SOURCE*

By

Sylvan Harris

(Managing Editor, Radio News)

The object of this paper is to present a simple method of calibrating a generator of low-frequency oscillations with a single-frequency source of oscillations, such as a 1000-cycle carbon contact tuning-fork. It is often required to calibrate such a generator, or to check previous calibrations, so that the author believes that a simple and accurate method will be welcomed by the many who do not wish to invest in the special and expensive apparatus generally used for this purpose.

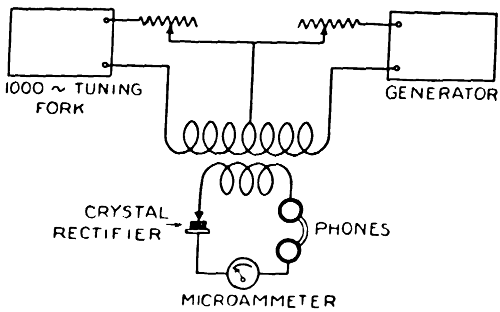

Figure 1

The tuning-fork and the low-frequency generator are both rich in harmonics, and the method makes direct use of these. The schematic set-up is shown in the illustration. The outputs of the generator and tuning-fork are combined in the transformer indicated (which is the ordinary transformer used in push-pull amplifiers), the secondary of which is in series with a crystal receiver, microammeter and telephone receivers. In the output leads of the generator and tuning-fork are resistances, which can be varied in order to adjust the outputs to the same order of magnitude. The reason for this is that, if the output

* Received by the Editor, December 30, 1925.

of the one is much greater than that of the other, the first is likely to mask the second, so that there will be no indication of beats in the microammeter or phones.

The presence of beats is indicated by a swaying of the microammeter needle, but, due to the sluggishness of the moving system of the meter, it is often difficult to detect the beats as they come into the audible range. For this reason the phones are included. It is not well to rely wholly on the phones, however, on account of aural fatigue.

Now let

a be the order of the tuning-fork harmonic
b be the order of the generator harmonic
f be the frequency of the generator, and
f_t be the frequency (fundamental) of the tuning-fork.

Then, the condition for exact resonance between the frequencies of the tuning-fork and the generator is expressed by

$$a f_t = b f$$

or,

$$f = \frac{a}{b} f_t$$

When the generator and tuning-fork are in operation, there will be, in general, a deflection of the microammeter needle, and two tones will be heard in the telephone receivers, corresponding to the fundamental frequencies of the generator and tuning-fork. No beats will be in evidence, however, until the condition expressed by the equation above is approached; the beat frequency will, in general, be above audibility, or too high for the needle of the meter to follow.

As the condition of resonance is approached, beats will be heard in the phones, and the meter needle will oscillate up and down, attaining its maximum amplitude of vibration, and greatest period, when exact syntony is attained. Theoretically, the needle should remain motionless at exact resonance, at a certain constant deflection which depends upon the phase relations, but such exact resonance is difficult to attain. It is often possible, however, to obtain a period of vibration of the needle of several minutes, and a very accurate adjustment can be obtained by noting the generator condenser values which give equal periods of vibration of the needle on either side of the position of zero beat. The value of the capacity for the zero beat condition can then be obtained as follows:

Let f_b be the beat frequency
c_o be the capacity corresponding to zero beat condition,

c_1 be the capacity corresponding to the beat frequency, f_b, when $af_t > bf$,

c_2 be the capacity corresponding to the beat frequency, f_b, when $bf > af_t$,

$$a f_t - b f = f_b$$

Substituting in this the relations for exact resonance, i.e.,

$$f_t = \frac{b}{a} f = \frac{b}{a} \frac{k}{\sqrt{c_o}}$$

we obtain

$$\frac{1}{\sqrt{c_o}} - \frac{1}{\sqrt{c_1}} = f_b$$

This relation holds when af_t is greater than bf. If the capacity is for an equal beat frequency on the other side of zero beat, we have

$$\frac{1}{\sqrt{c_2}} - \frac{1}{\sqrt{c_o}} = f_b$$

Equating these two expressions and reducing, we obtain

$$c_o = \frac{4\,c_1\,c_2}{(\sqrt{c_1} + \sqrt{c_2})^2}$$

This expression is rather cumbersome for ordinary use; a simpler expression is obtained by expressing the numerator as $2\,(c_1+c_2)^2 - 2\,(c_2{}^2 + c_2{}^2)$. Then substitute (c_1+x) for c_2 in the last term of this expression, expand the latter and drop the second power of x. Then

$$4\,c_1\,c_2 = 2\,(c_2+c_2)^2 - 4\,c_1\,c_2,$$

whence

$$4\,c_1\,c_2 = (c_1 + c_2{}^2).$$

Substitute this back in the original expression for c_o thus:

$$c_o = \frac{(c_1+c_2)^2}{(\sqrt{c_1}+\sqrt{c_2})^2} = (c_1+c_2)\left[\frac{(c_1+c_2)}{(\sqrt{c_1}+\sqrt{c_2})^2}\right].$$

Since c_1 and c_2 are always very nearly equal, the bracketed term is very nearly equal to $\frac{1}{2}$. The final expression then gives for c_o the arithmetical mean of the two other values, v!z.,

$$c_o = \frac{c_1+c_2}{2}$$

It is evident that a great many combinations of fundamental and harmonics may be obtained, and several combinations may be used for checking a particular frequency of the generator. It is often difficult to locate the beats when the harmonics are used, so for that reason it is well to anticipate their approximate location.

For instance, the beats resulting from the combination of the two fundamentals are easily detected on account of their great strength. The capacity of the condenser in the generator is

then noted. If it is desired to calibrate the generator at say, 857 cycles, with a tuning-fork whose fundamental is 1000 cycles, the approximate capacity required in the generator will be obtained by noting that the capacity required varies inversely as the square of the frequency. Upon setting the condenser at this value the beats will readily be detected by the meter or in the phones, with only very slight capacity change from this value.

The seventh harmonic of the generator will then be in resonance with the sixth harmonic of the tuning, for obviously,

$$857 \times 7 = 1000 \times 6$$

The table below gives the various frequencies at which the generator can be calibrated with a 1000-cycle tuning-fork using the harmonics up to the tenth. The spaces left blank indicate duplications; for instance, the same frequency can be checked for either $a=3$ and $b=4$ or $a=6$ and $b=8$, for obviously

$$\frac{a}{b} = \frac{3}{4} = \frac{6}{8}$$

One of the main advantages of the method is shown in the table—that using harmonics up to the tenth, 63 points can be determined on the calibration curve using only one constant frequency source, the tuning-fork. Another advantage of the method is that due to the fact that harmonics are *exact* multiples of the fundamentals, very accurate results can be obtained by this method without much trouble.

b	1	2	3	4	5	6	7	8	9	10
1	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
2	500		1500		2500		3500		4500	
3	333	667		1333	1167		2333	2667		3333
4	250		750		1250		1750		2250	
5	200	400	600	800		1200	1400	1600	1800	
6	166.6				883		1167			
7	143	286	428	573	713	857		1143	1286	1430
8	125		375		625		875		1125	
9	111	222		444	556		778	889		1111
10	100		300				700		900	

SUMMARY: **A simple method of calibrating an audio-frequency generator is described, a standard single-frequency source of oscillation being employed. The method makes use of the harmonics of the standard source and of the generator being calibrated.**

THE SHIELDED NEUTRODYNE RECEIVER*

By

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AND

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Since this is the first paper before the Institute of Radio Engineers dealing with the "Neutrodyne" receiver, it is thought advisable to include a brief historical outline of the development of this device.

In 1918, L. A. Hazeltine, then Professor of Electrical Engineering at Stevens Institute of Technology, and also serving in a consulting capacity to the Navy Department, was requested by the Navy Department to design a radio receiver. Among other things it was desired that there be no capacitive coupling between antenna and secondary circuits; for such coupling had been found to result in serious interference from nearby 600-meter transmitters when reception of signals from weak, higher wavelength stations was attempted. To accomplish the desired result—that of eliminating the capacitive coupling—the antenna tuning coil and condenser first were isolated from the secondary circuit by enclosing each in a separate compartment of heavy sheet copper. But a coupling coil, in series with the secondary, was needed in the compartment containing the antenna coil to give various degrees of inductive coupling, and the inherent capacity between these coils left a certain amount of capacitive coupling between their circuits. To eliminate this, Prof. Hazeltine wound another coil in close proximity to the coupling coil with one end free and the other connected to coupling coil. In addition to providing a shielding action, this coil was so proportioned as to number of turns and polarity that capacitive currents flowing from the antenna coil to it produced a magnetic effect equal and opposite to the effect produced by

* Presented at New York meeting, INSTITUTE OF RADIO ENGINEERS, February 3, 1926.

the capacitive currents which flowed from the antenna coil to the coupling coil directly. The result obtained was then the neutralization of an undesirable coupling capacity by another, or neutralizing capacity.

Late in 1922, Prof. Hazeltine designed, had built and successfully operated a radio-broadcast receiver. This experimental model employed two stages of tuned radio-frequency amplification, detector and two stages of reflexed audio-frequency amplification. The novel feature of this receiver was the neutralization of the capacity coupling between the successive tuned circuits by a method similar to the one employed in the Navy receiver. Since then many such receivers have been built and except for the abandonment of the reflex arrangement, no major changes have been found necessary. This is a most significant indication of the fundamental soundness of the original design.

The neutralization of capacity coupling in vacuum-tube amplifiers was first made public in a lecture before the Radio Club of America on March 2, 1923.[1] This was the advent of the Neutrodyne. It entirely changed the situation with regard to radio broadcast receivers. Prior to this time most of the receivers in use were the three-tube regenerative type. These receivers were sensitive and selective, but were objectionable because their adjustments were interdependent and therefore required skill to operate them. They also had the serious disadvantage of being able to produce oscillations annoying to the user, which also fed into the antenna and caused disturbance to others. Another objection is that of the distortion introduced, if regeneration is depended upon to secure maximum amplification and selectivity. The circuits then become too sharply tuned, which results in the elimination of the higher audio frequencies in the modulated wave. (The possibility of the occurrence of this same effect in tuned radio-frequency amplifiers in which regeneration is not used will be discussed later.) The Neutrodyne, however, possesses none of these disadvantages. The tuning adjustments are independent and, therefore, after a station has once been heard, the settings of the dials may be recorded for future use. No oscillations are employed and the receiver may be designed to have the right degree of selectivity without causing distortion due to cutting of the side bands.

Receivers of today of the better sort may be grouped into

[1] L. A. Hazeltine, "Proceedings of the Radio Club of America," Vol. 2, No. 8, March, 1923.

two main classifications: the tuned radio-frequency receiver, in which the signal is amplified at the frequency of transmission; and the super-heterodyne, in which the signal is first changed to a lower frequency and is then amplified. Regenerative receivers are still used, but in the better forms are provided with a tube or tubes whose internal grid-plate capacity has been neutralized to reduce the radiation. The tuned radio-frequency group includes the Neutrodyne and various other forms, which latter are known generally as "T. R. F. Receivers." In the latter attempts have been made to suppress undesirable oscillation due to regeneration, often by loss methods.

FUNCTIONS OF A BROADCAST RECEIVER. The broadcast receiver of the Neutrodyne type must perform the following functions:

The first function is to collect the signal on a suitable antenna.

The second function is to amplify the signal at radio frequency. In this process selectivity is obtained. That is, the amplifier, being a *tuned* radio-frequency amplifier, is selective against signals of different frequency from the desired one. The amount of amplification necessary is determined by the type of antenna used. In general, for best results, it should be sufficient, when adjusted to a maximum, to amplify signals which are only slightly stronger than the background level up to a point where the detector gives its normal output.

The third function is to rectify the amplified signal current—that is, to change it from modulated radio-frequency current to audio-frequency current.

The fourth function is to amplify the detector output current, which is at audio frequency, sufficiently to produce the normal output voltage at the loudspeaker. In general, it may be said that the maximum desirable audio-frequency amplification would be that which would amplify a normal detector output to a normal loudspeaker requirement. More than this is undesirable since tube noises and microphonic effects then become troublesome. Less than this is undesirable since the desired loudspeaker signal could then be attained only with an overloading of the detector tube.

The final process in reception, the conversion of the amplified electrical energy into sound energy, is accomplished by the loudspeaker. This process will be considered here only in its relation to the design of the receiver.

The Unshielded Neutrodyne

In obtaining the necessary radio-frequency amplification and selectivity for the receiver, cascade amplifiers employing the Neutrodyne principle are used. Cascade amplification requires several successive tuned circuits to be coupled together through vacuum tubes. To avoid regeneration and the resulting disturbing oscillation, it is necessary to eliminate all couplings between the successive circuits except the unilateral coupling of the vacuum tube itself. All other couplings are reciprocal, that is, may transfer energy in either direction. Any coupling which is capable of transmitting energy from one stage to a preceding one gives regeneration and results in undesirable sharpening of the tuning, or, if present in sufficient degree, results in the production of sustained oscillations which interfere with the signal being received, and also causes disturbances to others by radiation.

Prior to Professor Hazeltine's development of the Neutrodyne, the one coupling which stood in the way of successful cascade amplification was the coupling introduced in the vacuum tube itself by the capacity between grid and plate. His method of neutralization, when properly applied to a radio-frequency amplifier, eliminates the undesirable effects of this coupling.

Figure 1 illustrates the fundamental circuit.[2] If the nductances L_1 and L_2 are very closely coupled, a voltage devel-

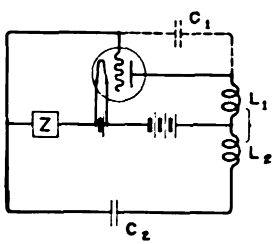

Figure 1—Fundamental Neutrodyne Circuit

oped in the plate circuit of the vacuum tube cannot produce an effect in the preceding grid circuit Z, provided the condenser C_2 is properly adjusted. This neutralization is independent of frequency. Some other forms of neutralization give the desired effect at the frequency to which the circuits are tuned, but are highly regenerative either in a positive or negative sense at other frequencies. This often results in the production of parasitic

[2] U. S. Patents 1,489,228 and 1,533,858.

oscillations which are very undesirable and prevent the cascading of units of this type into a multi-stage amplifier.

There are many other forms of coupling which must be eliminated in a successful multi-stage amplifier. It has been found that unless complete shielding is resorted to, only two stages of Neutrodyne amplification may be successfully used. However, two-stage amplifiers give a degree of amplification which is quite satisfactory if a good capacitive antenna is u ed Selectivity also is sufficient without at the same time being so great as to cause distortion due to the elimination of the side bands of the modulated wave.

Let us consider what other couplings may exist and have been eliminated in these unshielded receivers. There are three resonant circuits: one for the antenna and one for each of the stages of radio-frequency amplification. It is necessary that no magnetic coupling exist between any two of the three coils.

In Professor Hazeltine's design, he resorted to a novel arrangement. He developed mathematically the theorem that magnetic coupling between any number of symmetrical coils may be eliminated by placing them, with their axes parallel and at a certain angle[3] to a common line of centers. The mathematical assumptions made were not quite ideal, so that the true angle is not exactly the theoretical one, but it may be found readily. This arrangement of the coils has given a distinctive appearance to the unshielded type of neutrodyne receivers. It allows the use of single-layer cylindrical coils, which have proven to be the most efficient type of high-frequency inductance that can be put in a given space.

Magnetic coupling between stages may also be eliminated by placing the three coils mutually at right angles or by the use of some special form of coil which has a confined magnetic field. Arrangements of this kind have certain advantages in that they do not pick up, magnetically, signals from strong local stations.

If the second or third coils in the customary Neutrodyne do pick up from strong local stations, it may, in some instances, cause interference because of the fact that a signal picked up in this way is not subjected to the highly selective action of all three of the tuned circuits. However, all inductances of the last mentioned type, if of the same physical dimensions as the cylindrical coils, have, of necessity, higher electrical resistance. Their use, therefore, results either in less amplification or poorer selectivity or in both.

[3] Angle whose tangent is $\sqrt{2} = 54.7.°$

Another coupling that may exist between the tuned circuits is that introduced by inherent capacity. Capacity between adjacent stages enters in the balance obtained with the neutralizing condenser. Capacity of this kind is less desirable than the ordinary neutralizing capacity, as is explained below in connection with Figures 2 and 3. The secondary coils themselves cannot be extremely closely coupled to the primaries, and therefore this capacity introduces neutralization of a less desirable kind.

Capacity between non-adjacent stages (between first and last coils in a three-circuit unshielded receiver) may result in appreciable regeneration and in oscillation when the total radio-frequency amplification is increased beyond a certain point. Many Neutrodyne receivers are supplied with a third neutralizing condenser which neutralizes this over-all capacity. These receivers may obtain a somewhat higher degree of amplification than receivers which are not so supplied.

It should be pointed out also that if a three-stage receiver is planned, four tuned circuits would have to be employed. In order to properly neutralize all capacitive couplings between such circuits, six neutralizations would be required. This becomes unwieldy and has led to the conclusion that if three or more stages are required, complete metallic shielding must be resorted to.

There are other incidental couplings which must be eliminated to produce a successful receiver. Couplings introduced by the use of common batteries and couplings introduced by poor arrangement of wiring and auxiliary apparatus, have all been discussed in detail before.[4]

As has been mentioned before with regard to Figure 1, it is desirable to have close magnetic coupling between the coils L_1 and L_2. Figure 2 illustrates diagrammatically the effect of departure from this relation. In this figure, a vacuum tube employing a tuned grid circuit feeds an ideal transformer (transformer having unity coupling) through an inductance L_o, which represents the action of the leakage inductance which is present in an actual transformer. In this case the capacity C_2, may be adjusted for a balance when the tube is unlighted. This balance, however, is not independent of frequency, because it is a balance between a pure capacity C_2 on one hand and the capacity plus the leakage inductance on the other hand.

[4] J. F. Dreyer, Jr. "Proceedings of the Radio Club of America," Vol. 3, No. 3, May, 1924.

This effect is not of serious import in the unshielded Neutrodyne since the leakage inductance, L_o, is always small. The capacity C_1 is also small and its reactance is always high compared to the reactance of the inductance L_o.

There is another effect, however, which causes the balance to be less than perfect. This is the effect of the plate impedance of

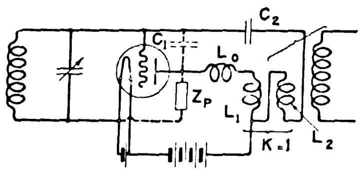

FIGURE 2—Effect of Lack of Unity Coupling

the tube which in effect is connected between the junction point of C_1 and L_o, and the ground potential terminal of inductance L_1. Current flowing through this impedance is in nearly 90°phase relation to the current flowing through C_1. This causes a voltage to be developed in L_o which cannot be neutralized by the capacity C_2. This effect is also small in the customary Neutrodyne design and if L_o is minimized by close coupling between L_1 and L_2, does not result in appreciable regeneration.

In the unshielded Neutrodyne, it is difficult to take full advantage of the principle of close magnetic coupling between the inductances L_1 and L_2 for the following reason: Consider Figure 3, which represents a customary arrangement. The primary of the trans-

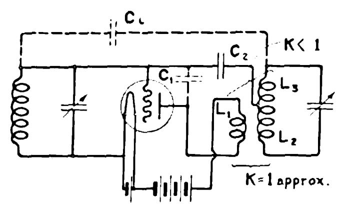

FIGURE 3—Effect of Inherent Capacity Ci

former L_1 may be very closely coupled to the neutralizing section of the secondary L_2. However, L_1 cannot be so closely coupled to the entire secondary (L_2 plus L_3) without the introduction of undesirably high capacity and dielectric loss. There is, of necessity, a certain amount of inherent capacity (C_i) between the upper end of the secondary (L_2 plus L_3) and the preceding grid circuit. The fact that this capacity is present causes the neutralizing

capacity C_2 to be smaller than it would be otherwise. In other words, the inherent capacity C_i enters into the balance. The fact that it is present may be considered electrically as introducing additional leakage inductance in the plate circuit of tube. This is undesirable, as has been stated before.

Use of Shielding

Figure 4[5] illustrates diagrammatically the arrangement of one stage of a multi-stage amplifier, in which the metallic shield minimizes all other couplings and the neutralizing coil L_2, together with the condenser C_2 eliminates the effect of the tube capacity.

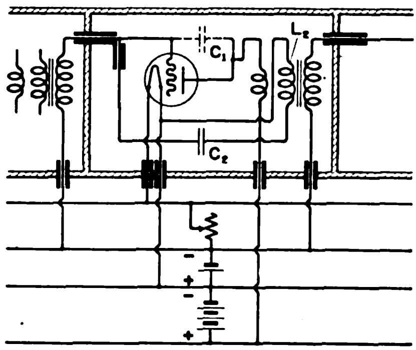

FIGURE 4—Shielded Stage of a Multi-stage Amplifier Proposed by Prof. Hazeltine in 1919

Viewed broadly, this is the ideal solution of the multi-stage amplifier problem. The magnetic and dielectric fluxes associated with each stage are well isolated from all other stages by the metallic shielding. The magnetic flux which penetrates low-resistance shielding is very small—so small that it is unnecessary even in the compactly-built receivers, to take precautions such as placing the coils at critical angles. All capacities existing between adjacent stages or between non-adjacent stages are completely eliminated, except, of course, the capacity introduced by the elements of the vacuum tube, together with the capacity between the input and output circuit within the stage. This last is completely and properly neutralized by the condenser C_2 and the closely coupled inductance L_2.

The use of metallic shielding in vacuum tube amplifiers and

[5] U. S. Patents Nos. 1,489,228 and 1,533,858.

that of a third or neutralizing coil were among the arrangements originally suggested by Prof. Hazeltine.

Referring back to Figure 3, it should be noted that the interposition of a metallic shield in the manner illustrated in Figure 4 eliminates the undesirable capacity C_i, so that all of the neutralization is accomplished by C_2. The coil L_2 of Figure 4 may be closely coupled to the primary coil without introducing undesirable capacity. This results in almost complete elimination of the leakage inductance L_o, Figure 2, and, therefore, in the elimination of the undesirable effects which accompany this inductance.

It has sometimes been thought that metallic shielding placed in close proximity to the inductance coils would result in the introduction of serious losses. Measurements, however, indicate that this is not the case. Figure 5 illustrates how the losses

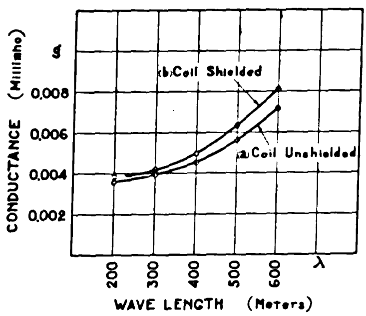

FIGURE 5—Losses of a Resonant Circuit

(given in terms of equivalent conductance at resonance) vary over the broadcast wavelength range.

Curve *a* represents the variation in loss of a resonant circuit consisting of a single-layer inductance, 80 turns of No. 24 A. W. G. double cotton-covered copper wire on a 2-inch diameter tube tuned with a 500-micromicrofarad air condenser.

Curve *b* shows the slight increase in loss caused by enclosing the inductance in a sheet copper box whose walls were 0.019 in. thick and separated by about 1 in. in all directions from the windings. The increase in loss is due mainly to the decrease in inductance, which necessitates the use of a higher capacity at a given wavelength. ($g = \frac{C\,r}{L} = \omega^2\,C^2\,r = \frac{r}{\omega^2\,L^2}$ where g is the conductance, C the capacity, L the inductance, r the effective series resistance and ω the angular frequency.)

Another argument advanced against the use of shielding, and which was quite pertinent, was the fact that the eddy current set up in the metal by the magnetic fields of the coils might circulate to the shielding of preceding stages and by their own magnetic effect cause undesirable coupling. It was this effect which caused the failure of partly shielded Neutrodynes. Such currents, however, are confined locally, if separate metallic containers are used for the separate stages or if the shielding is built into a single unit of low-resistance short-circuiting paths.

Many also were afraid of the prohibitive costs of metallic shielding. However, when it is considered that copper or brass, which are commonly used for this purpose, are excellent structural materials, on a strength basis, this cost argument loses its force.

Development of the Three-Stage, Completely Shielded Neutrodyne

The above considerations and others point to the desirability of isolating the separate stages of the amplifier from one another by metallic shields. Having decided to do this, let us consider the design of a broadcast receiver of such a type.

First, the use of shielding makes it possible to increase the number of stages. The use of three stages of "Shielded Amplification" results in a total radio-frequency amplification which, when a small capacity antenna is employed, is sufficient to meet ordinary requirements. Three steps necessarily result in four tuned circuits which, if separately controlled, would be undesirable from the operator's standpoint. However, the last three tuned circuits may be made identical. A vacuum tube precedes each stage and follows each stage and, therefore, with proper care in the mechanical design and a slight change in the electrical design of the transformers, it becomes quite practicable to tune all three of these circuits with a single control.

The antenna circuit, however, is inherently different from the other circuits in that no tube precedes it. Also, it may be desirable to use a loop type antenna whose minimum capacity is likely to be variable. For this reason, it is most desirable to tune this circuit with a separate condenser. When this is done, all precautions may be taken in order that the antenna circuit may have a low a resistance as possible and thus contribute to the selectivity of the receiver as a whole.

The three other circuits, since they are controlled with a single adjustment, must be so designed as to have individually a

broader resonance curve than the circuits employed in the unshielded receiver. This can be done without serious sacrifice in amplification and with an actual gain in uniformity over the wavelength range by the use of a transformer designed as follows:

Figure 6 illustrates such a transformer. The primary and neutralizing windings are wound on an inner cylindrical tube which has been threaded with a double thread. The number of primary turns is considerably increased above that used in the unshielded type of receiver. The secondary coil is wound on a threaded tube which fits closely around the inner tube. It must be designed to have a lower inductance than would be required in an

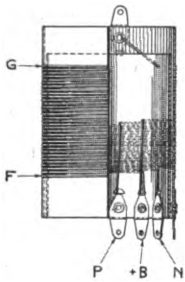

FIGURE 6—Arrangement of Inter-stage Transformer

unshielded transformer, because of the fact that relatively high number of primary turns and close proximity of these turns to those of the neutralizing winding result in a high minimum capacity of the circuit as a whole. This requires the use of a larger tuning capacity than would otherwise be required.

The high minimum capacity also introduces dielectric losses which are more important at the high-frequency end of the scale than at the low. This results in a flatter conductance curve, and, since the amplification is a function of the conductance, the amplification of the transformer, as a whole, is more nearly uniform.[6] This arrangement of the primary and neutralizing winding results in a very high coefficient of magnetic coupling between these circuits; in this way the full advantage of the Neutrodyne method of capacity neutralization may be realized.

Figures 7 and 8 illustrate the performance of two types of transformers. Figures 7a and 8a illustrate the amplification per

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[6] Amplifications $\frac{\tau\mu g_p}{g_p+\tau^2 g}$, where τ is the effective turns ratio, secondary to primary; μ the amplification factor of the tube; g_p the plate conductance of the tube, and g the conductance of the tuned circuit at resonance.

stage and resonance curve of a transformer suitable for a two-stage unshielded receiver. Figures 7b and 8b illustrate the same properties of a transformer suitable for a three-stage shielded receiver. It should be noted that the three-stage transformer

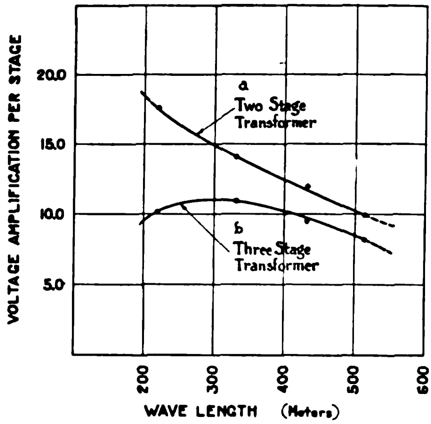

FIGURE 7—Voltage Amplification per Stage of Radio Frequency Transformers

has a considerably broader resonance curve and hence is more easily adaptable for use with "gang" controlled condensers. The

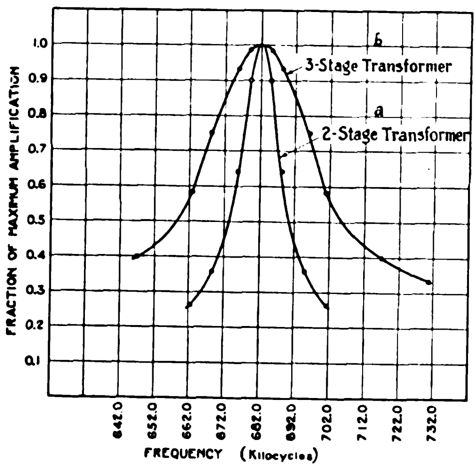

FIGURE 8—Resonance Curves, Tuned Radio Frequency Transformers

loss in amplification is more than made up by the additional stage.

In multi-stage amplifiers certain other precautions in the wiring and arrangement of circuits is necessary to prevent

incidental couplings of the type mentioned before when discussing the unshielded receiver. Figure 9 illustrates diagrammatically the ideal arrangement of two of the stages of a multistage amplifier showing the necessary by-passing and filtering

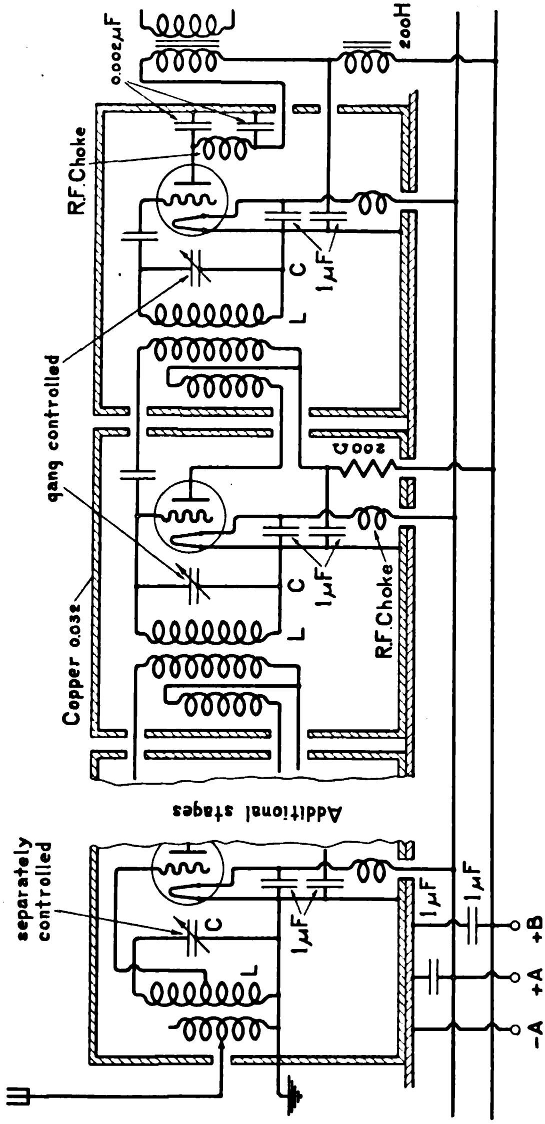

FIGURE 9—Arrangement of a Multi-stage Neutrodyne

that is required in the battery leads to prevent radio-frequency currents from passing out of the separate compartments and intermingling. This diagram illustrates the ideal arrangement

and some of the precautions illustrated here are not necessary in a three-stage receiver. They become of more and more importance the higher the total amplification, and all of them appear to be necessary in a four-stage receiver.

Even with precautions of this type there seems to be an upper limit to the amplification that may be obtained at the broadcast frequency. This limit is not reached with a three-stage receiver but may be with a four-stage. It appears to be due to radio-frequency potentials which build up upon the shielding of the last stage. These potentials are capable of feeding back energy to the antenna through the inherent capacity between these shields and the antenna. They are due to the capacitive and magnetically induced currents in the shielding. It is possible that this limitation may be removed by the use of double shielding. Fortunately, however, it occurs only when the total voltage amplification obtained is over 10,000. This is more than can be usefully employed in broadcast receivers.

Another limitation of considerable importance is that imposed by the variation in tube-coupling capacity. Receivers are balanced for normal tubes, but due to the lack of uniformity of tubes as delivered to the purchaser, allowances for such variation must be made.

Regeneration or oscillation, if present, due to inexact balance, is most noticeable in the first circuit, since no tube precedes it and since this circuit is of lower resistance than the others. It is desirable, therefore, to sacrifice somewhat the amplification of this stage, in order to gain stability against variation in tube capacity (tube tolerance). This may be done by connecting the grid of the first tube to a tap at the centre of the first inductance coil.[7]

Briefly, then, the advantages of shielding as applied to Neutrodyne receivers, are as follows:

1—Due to the removal of stray capacity and inductive couplings, the use of shielding makes possible the construction of three or four-stage tuned radio frequency amplifiers.

2—With complete shielding, perfect neutralization may be obtained.

3—Magnetic or capacity pick-up of interfering signals on intermediate circuits, is eliminated.

4—The number of tuning adjustments may readily be reduced to two.

[7] This arrangement is due to Mr. W. A. MacDonald.

Audio-Frequency Amplifier

In considering completely a radio receiver, some mention must be made of the audio-frequency amplifier employed with it. It is regrettable that in the past very little emphasis has been put upon the design of the audio-frequency portion of many receivers.

For satisfactory reproduction, audio-frequency amplifiers must satisfy two main requirements. First, they must be able to deliver to the loudspeaker as high an output as is desirable without the introduction of undesirable harmonics. In many amplifiers, undesirable harmonics are produced by overloading in the grid and plate circuits of the last tube even on moderate volume requirements. This limitation may be completely removed by the use of higher power vacuum tubes (tubes whose filaments have higher total emissions) together with the proper "B" and "C" voltages. If the user is content with moderate volume, an amplifier employing the 201-A and 112 type tubes may be made quite satisfactory.

The second main requirement of an audio-frequency amplifier is that it must have a proper amplification frequency characteristic curve, which when combined with the characteristic curve of the radio-frequency circuits and the loudspeaker, will result in a satisfactory over-all performance. It goes without saying that this frequency characteristic should be invariable and not dependent on circuit conditions. This is not always the case in conventionally designed amplifiers.

In transformer coupled audio-frequency amplifiers, the individual transformers must be carefully designed so as to have sufficient impedance at the lower audio frequencies to prevent a fall in amplification at these frequencies. Also, the distributed capacity and leakage inductance in the secondary must be considered, in order that the transformers shall not have a greatly exaggerated amplification at these higher speech frequencies (the resonant frequency of the secondary leakage inductance with the distributed capacity of the secondary). There are various methods of removing this "second peak." It is felt, however, that too much stress has been laid in the past on the frequency characteristic of the individual transformers. The characteristic of the amplifier, as a whole, may be much distorted by regeneration at audio-frequency. Figure 10 illustrates some of these effects. Curve (*a*) is the characteristic of an amplifier with all regenerative actions suppressed. Curves (*b*) and (*c*) show the characteristic of the same amplifier with distortion resulting from regeneration

due to impedance in the common "B" current supply. Impedances sufficient to cause this type of distortion may be found in dry "B" batteries after a few weeks' use or in "B" socket power devices from the start. This type of distortion is probably the most common source of dissatisfaction with amplifiers now on the market. It may be removed by the use of a separate detector

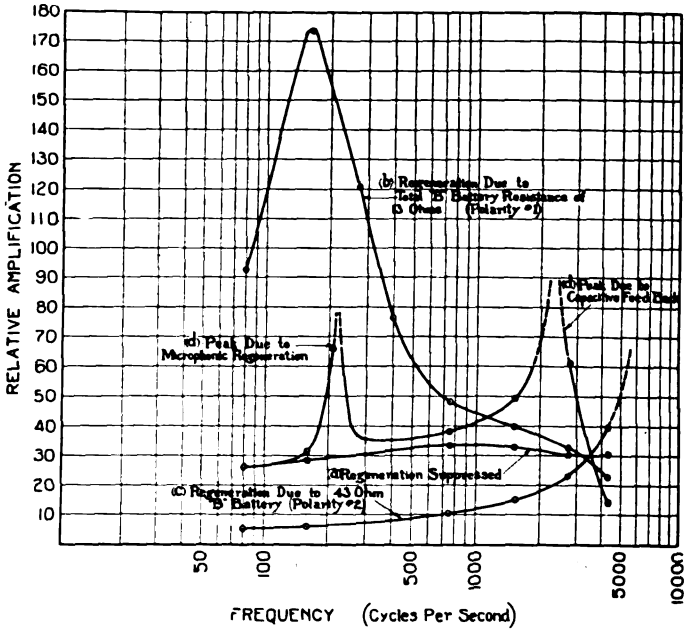

FIGURE 10

"B" unit or by proper filter arrangements which are now being investigated.

Curve (*d*) illustrates a distortion arising from capacity coupling between the output of the last tube and the detector grid, if grid-circuit detection is used. This may be entirely removed by shielding the detector tube in a metal compartment, or by the use of plate-circuit or mutual detection.

Curve (*d*) also illustrates a distortion arising from mechanical regeneration from the loudspeaker to the elements of the detector tube. The use of spring cushion sockets is helpful in preventing this type of distortion, but not wholly satisfactory since the vibration may sometimes be transmitted through the air. When springing is resorted to, the mechanical frequency of the device should be below the audible range. Felt-lined compartments for

detector tubes are helpful in minimizing this effect. In some cases rigid mounting of the tubes is desirable.

Distortion of this latter type may be caused by microphonic action of the radio-frequency tubes or even of the tuning condensers. The action is then a modulating one and only occurs when a carrier frequency is present.

If any of the above-mentioned effects are present to an extent slightly greater than illustrated, continuous howling takes place. When this occurs, it becomes at once apparent. It is desired to emphasize the fact, however, that distortion may occur from these effects even though no continuous oscillation or howl takes place.

The proper shape of the most desirable audio-frequency characteristic curve depends largely upon the loudspeaker. Those of the paper cone type are satisfactory, but even these seem to over-emphasize the higher frequencies. This is partially corrected by the radio-frequency circuits. It has been found necessary, however, for most pleasing results, to diminish the high frequencies to a still greater extent. This may most conveniently be done by the use of a condenser of the order of 0.01 microfarad in parallel with the loudspeaker. Suppression of the higher audio frequencies by this method is helpful in minimizing interference from stray disturbances since they appear principally as high audio frequencies.

Commercial Design of a Shielded Neutrodyne Receiver

One of the first designs of totally shielded Neutrodyne receivers to be manufactured was a six-tube model, which was first produced in quantities in the fall of 1925. It serves as a good example of the principles just enumerated for a three-stage shielded Neutrodyne receiver.

In general, this receiver consists of three stages of tuned radio-frequency amplification, a vacuum-tube detector and two stages of transformer-coupled audio-frequency amplification, the four tuned radio-frequency circuits and accompanying apparatus being enclosed in individual shields.

Receiver Circuit. A simplified circuit diagram of this receiver is shown in Figure 11. It will be observed that each of the three radio-frequency tuning circuits is enclosed in a separate shielded compartment which contains the following apparatus:

(*a* Radio transformer of the general design shown in Figure 6.

(*b*) Variable tuning condenser (Figure 17).

(*c*) Tube Socket and Vacuum Tube.

(*d*) Neutralizing condenser of the design shown in Figure 22.

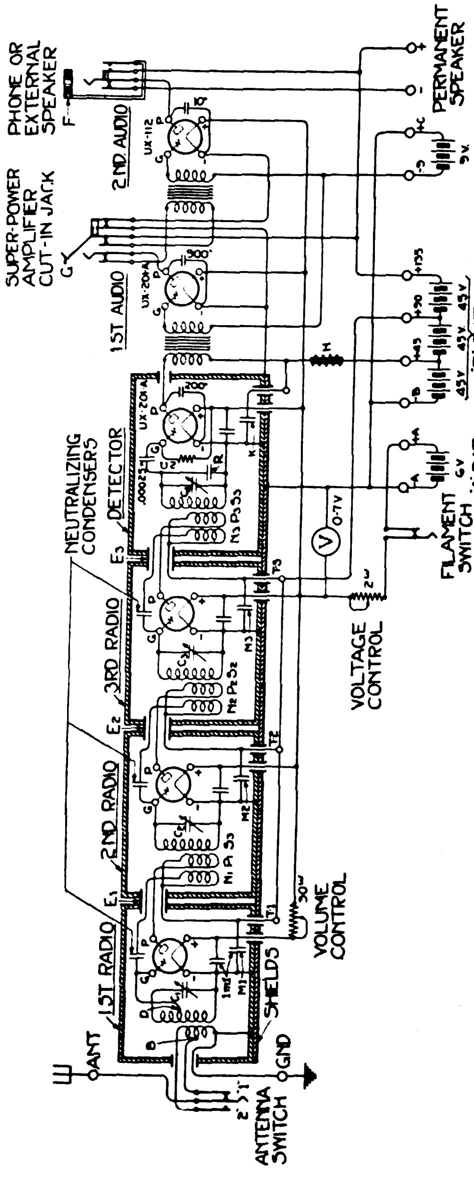

FIGURE 11

(*e*) Fixed by-pass condenser (1 m.f.) for the "A" battery supply leads.

(*f*) Fixed by-pass condenser (1 m.f.) for the "B" battery supply leads.

The detector-shielded compartment contains, in addition to the above apparatus, the following:

(*g*) Condenser R of the type shown in Figure 22, connected across the variable condenser of the fourth tuning stage, to raise its capacity to that of the preceding three tuning stages, which already have in effect similar increase in capacity due to the neutralizing condensers, also of the type shown in Figure 22.

(*h*) Fixed grid condenser of 0.00025 mf. capacity.

(*i*) Fixed by-pass condenser of 0.002 mf. capacity.

(*j*) Grid leak of 2 megohms resistance, connected between the grid and the "+F" terminal of the detector socket.

As previously explained, the use of the individual shields and the several by-pass condensers confines the action of each radio-frequency tuning and amplifying stage within its particular shield and thereby avoids inter-stage and over-all couplings. Additional precautions against these couplings are provided by shielding the three wires that inter-connect the shielded radio amplifier compartments, as shown at E_1, E_2, and E_3 in Figure 11.

No shielding is used for the audio amplifier system of this receiver, due to the fact that that portion of the circuit is sufficiently stable in itself and to the fact that the remainder of the receiver, including the detector circuit apparatus, is completely shielded.

Further consideration of the circuit, Figure 11, shows the following features:

1—A switch for connecting the antenna to the complete primary or to a tap "B" in the primary winding of the first radio transformer, so as to accommodate different sizes of antennas and provide increased latitude of sensitivity and selectivity in the operation of the receiver.

2—The use of the scheme, previously described, of connecting the grid of the first radio tube to a mid-tap *D* of the secondary winding of the first radio transformer, to gain stability against variation in tube capacity.

3—The provision of a by-pass condenser across the output circuits of each of the audio amplifier tubes, for

cutting down the higher audible frequencies to compensate for over-emphasis of these frequencies in some types of loudspeakers, as previously described.

4—The provision of three output connections for various types of reproducers, as follows:

(*a*) Binding posts connecting to the output of the second audio tube for a permanently wired loudspeaker.

(*b*) A cut-in jack *F* located on the front panel of the receiver, to which an external loudspeaker or a radio headset can be connected and at the same time cut off the circuit to the permanently-wired loudspeaker.

(*c*) A cut-in jack *G* located on the terminal board at the rear of the receiver, to which any one of the various so-called "Super-Power" amplifier equipments can be attached. It will be noticed that the inserting of a radio plug into this jack cuts off the second audio tube and connects the external amplifier to the output of the first audio tube, thereby providing the one stage of audio amplification that is required between the detector and the super-power amplifier to prevent overloading of the detector tube.

5—A filament "voltage control" consisting of a rheostat connected in series with the "A" current supply to all six tubes, with a voltmeter *V* on the filament side of the rheostat. The voltmeter is provided with a red line at the 5-volt division and has printed on its face in large type the following wording, "*Keep pointer to left of red line.*" It has been found in service that the voltmeter serves several useful purposes, as follows:

(*a*) Avoids over-voltage on tube filaments, giving longer active life for all tubes in the receiver.

(*b*) Indicates condition of battery.

(*c*) Serves as a visual indication that the receiver is connected for operation.

6—A "volume control" consisting of a rheostat for regulating the filament current supply to the first radio amplifier tube. By regulating the strength of signal at the first shielded compartment, it is possible to get a wide range of volume control and avoid the

detector tube overload distortion that is encountered when the voltage control is located at or after the detector tube. This type of volume control is made feasible by the shielding of the radio stages which prevents couplings of succeeding radio stages back to the antenna. Incidentally, the variation in current supply to the first tube filament, due to this volume control, does not change the voltage on the filaments of the remaining five tubes by a sufficient amount to require correction at the voltage-control rheostat.

7—The use of a third or neutralizing coil N_1, N_2 and N_3 for each radio-frequency transformer, as previously described in connection with Figure 4.

8—The providing of an impedance coil H in the detector tube plate current feed, which, combined with the 1-mf. by-pass condenser connected between this coil and the primary of the first audio transformer and the shielding of the detector tube enclosure, serves to prevent audio regeneration, when the B current supply has a high impedance, as previously explained in connection with Figure 10. This arrangement is due to Mr. H. A. Wheeler.

Station Selecting System. The wiring diagram, Figure 11, shows four tuning circuits, normally requiring four station selecting controls, one for each of the variable condensers C_1, C_2, C_3 and C_4. A receiver made with these four controls would involve no special mechanical design or difficult manufacturing methods in its production. However, providing the three tuning condensers C_2, C_3 and C_4 with a common drive, leaving the antenna tuning condenser on a separate control, so as to reduce the station selector controls to two, as previously described, introduces some mechanical problems that require special treatment. It is obvious that all three of the tuning coils used in the 2nd, 3rd and 4th tuning circuits must be alike in inductance and that three associated capacities also must be alike for each setting of the station selector throughout the complete scale.

The construction of the tuning system must be such that it will not be disturbed by rough handling during shipment or by subsequent wear of the driving mechanism or by mechanical displacement through temperature changes. The requirement that each of the three tuning condensers be enclosed in individual shields, also complicates the problem.

In this six-tube shielded Neutrodyne receiver, these problems have been solved by employing a chassis construction that is entirely new to radio receiver design. A heavy steel angle-iron framework, with suitable steel cross members, shown in Figure 12, serves as a base upon which all operating apparatus is

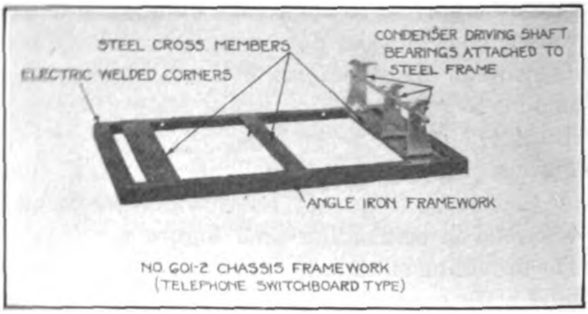

FIGURE 12

mounted. The complete chassis assembly, with tops of the shields removed, is shown in the two views, Figures 13 and 14.

The three tuning condensers C_2, C_3 and C_4 are driven by a solid one-piece 5-16 inch diameter steel shaft, which extends

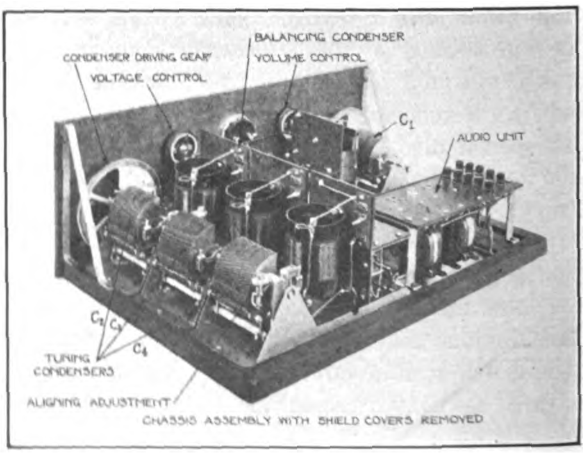

FIGURE 13

rom the station selector dial pointer, through the hollow sleeve shafts of the separate condensers and the three main shaft supporting bearings, as illustrated in the cross-section diagram Figure 15.

A view of the main driving shaft and the three bearing brackets, which are assembled directly on the chassis, is shown in Figure 16. An adjustable, flexible, spring-type bearing is employed to provide against shaft looseness, due to wear. This type of bearing adjustment is shown more clearly in Figure 18.

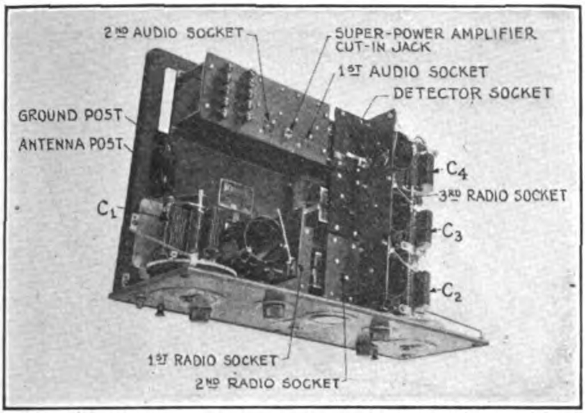

FIGURE 14

The one-piece driving shaft construction is made possible by using a hollow sleeve type of rotor shaft on each tuning condenser, as shown in Figure 17, and in the diagram, Figure 15. This allows individual condensers to be assembled and accurately

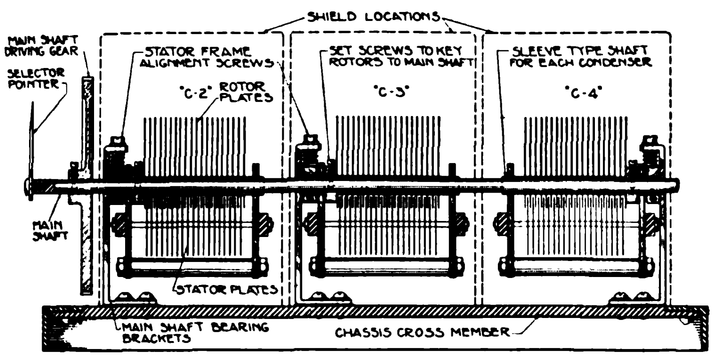

FIGURE 15

adjusted before mounting, the same as for any single-type variable condenser, and later slid on to the one-piece driving shaft and locked to the latter by two hardened steel set screws as shown in Figure 15. Thus, the one-piece shaft serves mainly as a means

for revolving the three condenser rotor plate assemblies, providing positive drive, not unlike that employed in the so-called "full floating rear axle" of a modern automobile. This construction also simplifies the mounting of the three variable condensers in separate shielded compartments.

While the construction just described provides for driving

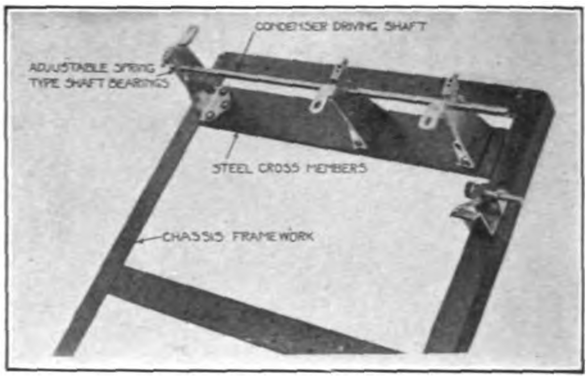

FIGURE 16

all three sets of rotor plates in unison, the scheme is made still more practical by adjustably fastening each condenser frame (stator assembly) to the main drive shaft-bearing bracket, as

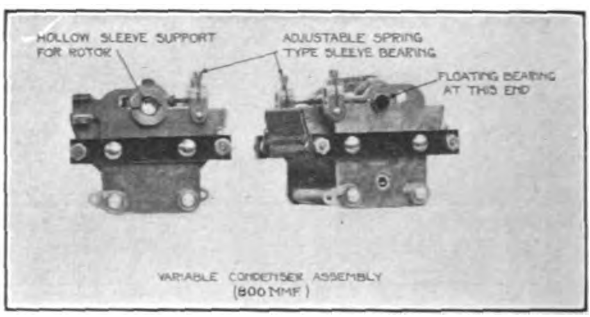

FIGURE 17

shown in Figure 18. An adjusting screw (A) passes through a clearance hole in the lug B of the main bearing bracket and threads into the lug D of the tuning condenser frame (stator assembly). A spiral spring C serves to swing the condenser assembly counterclockwise, when the adjusting screw is turned in a counter-

clockwise direction and vice versa, as well as to maintain the adjustment against looseness. This adjustment provides a simple and accurate means for condenser alignment, as subsequently described.

CONSTRUCTION OF TUNING CONDENSERS. The mechancial accuracy in the construction of individual condensers to provide

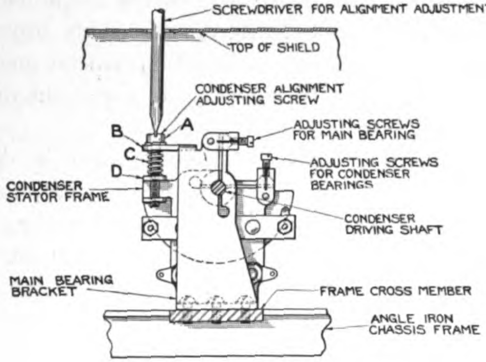

FIGURE 18

for sharp tuning at each setting of the station selector control is attained as follows:

(*a*) By the use of flat heavy-gage brass plates, assembled in accurate spacing fixtures and soldered together through overlapping lugs provided on the edges of the plates.

(*b*) By employing wide spacing between plates.

(*c*) By the use of a large number of plates, 19 stator and 20 rotor plates per condenser.

(*d*) By adjusting for trueness of plates while rotating.

(*e*) By the use of spring-type bearings as shown in Figure 18, to avoid looseness due to wear.

(*f*) By taking all end-thrust of rotor shaft at one bracket of the condenser frame, the bearing at the other bracket being allowed to float.

These precautions in design and assembly of the variable condensers make it possible to pick, by suitable test methods, condensers for any one shaft assembly that have less than 0.4 per cent. total variation, this being found sufficient accuracy to provide a wide factor of safety for succeeding operations and for any changes that can occur, due to wear while in service.

The maximum capacity of these condensers is approximately 800 mmf., this being required, due to the high minimum capacity

of the circuit when the condenser rotor plates are out of mesh with the stator plates.

TYPE OF CONDENSER USED. It should be noted here that the type of condenser employed is the straight-line-capacity design, thereby giving equal changes in capacity in all three condensers on the common drive shaft for each division of the tuning scale, regardless of whether the stator and rotors of the three condensers are in exact mechanical alignment. This provides for an electrical alignment of condensers, which can be made after the shields are in place, so as to compensate for slight differences in the three shielded compartments.

The straight-line-capacity condenser also is desirable for completely-shielded type receivers, due to compactness. The present congestion of broadcast stations on the lower wave lengths makes it difficult to successfully bring in distant stations on the channels between 200 meters and 280 meters without interference. Usually, only a few powerful or nearby stations in this range can be selected with any degree of freedom from beating between transmitted carrier waves.

The tuning system of this receiver has been designed so that the broadcast range, 200 to 550 meters, just fills the station selector scale, allowing about 3 or 4 divisions at each end for manufacturing variations.

The station selector pointer is keyed and fastened directly on the end of the condenser driving shaft, avoiding lost motion that otherwise would cause inaccuracy in logging station settings. The operation of the station selector is made positive by use of a 10-to-1 reduction gear between the operating knob and the condenser driving shaft. It is felt that this arrangement results in a satisfactory spacing of the broadcast channels even with the use of a straight-line-capacity condenser.

CONSTRUCTION OF RADIO TRANSFORMERS. All four of the tuning coils used in this receiver are of the type described in the first part of this paper and shown in Figure 6.

The primary is wound on a cylindrical formica tube 2½ inches in outside diameter with 20 double threads per inch cut in the outside surface to accurately locate the turns of the single-layer winding. As will be noticed from Figure 11, the antenna transformer has a single inner winding while the other three tuning stages have two inner windings. In these latter three transformers, the two wires of the two inner windings are wound together in adjacent grooves of the double thread, thereby giving a close coupling between the primary and the neutralizing winding. These

two windings are made with No. 29 A. W. G. double-silk-covered copper wire.

The secondary is wound on a cylindrical formica tube 2¾ in. in outside diameter with 24 threads per inch cut into the outside surface to accurately locate the turns of the single-layer secondary winding. This winding is made with No. 20 A. W. G. black-enamel copper wire.

By maintaining mechanical accuracy in the coil tubes and the winding, it is possible to keep the completed coils well within a 0.2 per cent. inductance variation.

The primary coil tube fits closely inside of the secondary coil tube and the assembly is mounted vertically within the shielded compartments as shown in Figure 13. The individual shields prevent any noticeable magnetic coupling between coils.

CONSTRUCTION OF SHIELDS. The individual shields of this receiver are made in three parts, the bottom, the rectangular box-shaped top, and the cylindrical-shaped tube cover, as illustrated in Figure 19.

The shield bottom is constructed of heavy gage brass (0.040 in. thick) and serves as a support for the tuning coil, tube socket

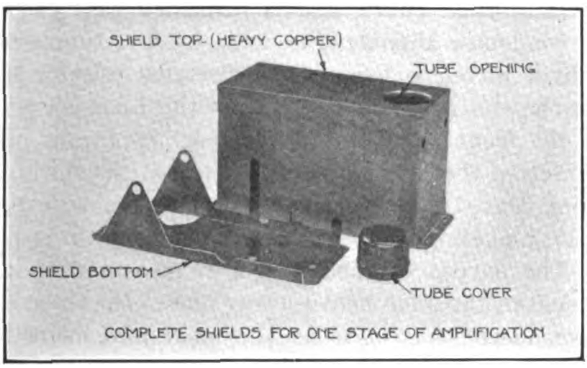

FIGURE 19

shelf, and two large fixed by-pass condensers, as illustrated in Figure 20.

The shield top is constructed of heavy gauge sheet copper (0.032 in. thick) with a polished copper surface inside and a tinned surface outside, the latter to facilitate soldering the seams when assembling this portion of the shield. The rectangular top shield fits closely over the bottom section with an overlap of ½ in. all around.

The tube cover is drawn from one piece of heavy brass or copper and is designed to fit the tube opening in the rectangular shield top.

FACTORY TESTS AND ADJUSTMENTS. Besides the tests for accuracy of the variable condenser capacity and tests for the electrical constants of the tuning coils, it is necessary to electri-

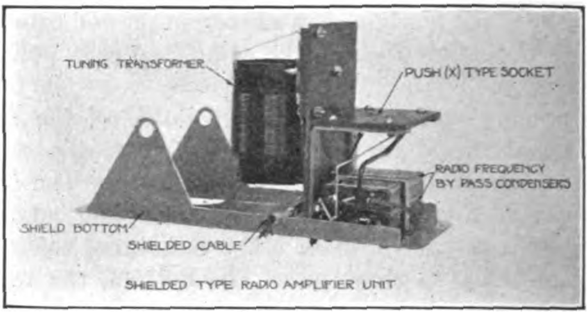

FIGURE 20

cally align the second, third and fourth tuning condensers, to neutralize the three radio amplifier stages, and to obtain readings for the calibration curve that is furnished with each receiver.

The condenser alignment is made by first tuning-in a signal at the high wavelength end of the station selector scale, then rotating the stators of the second and third condensers (the two nearest the front panel of the receiver) by means of a screwdriver inserted through a hole in the top of the shield, as shown in Figure 21. The screwdriver engages the adjusting screw, Figure 18, and allows for changing the stator with respect to the rotor. The output of the receiver is measured by a thermogalvanometer, the alignment for any one of the three condensers being considered correct when the maximum meter reading is obtained.

The fourth tuning stage, located in the detector shield, usually is adjusted first, by changing the capacity of the "padding" condenser, R, Figure 11, so as to give the proper top and bottom selector scale margins for the broadcast wavelength band.

After aligning at the high end of the scale, the accuracy of alignment at the other end of the scale is checked by the thermogalvanometer method just described.

The neutralizing operations follow the regular practice excepting that it is not convenient to block the filament connection in the new X-type of tube sockets, which are employed in this

receiver. Instead, the "+B 90-volt" current-supply wire is disconnected from a terminal, T_1, T_2 or T_3, Figure 11, provided on the bottom of each of the radio amplifier shields. By referring to the circuit, Figure 11, it will be noticed that the radio-frequency circuit is left intact when this B-battery circuit is opened, it then

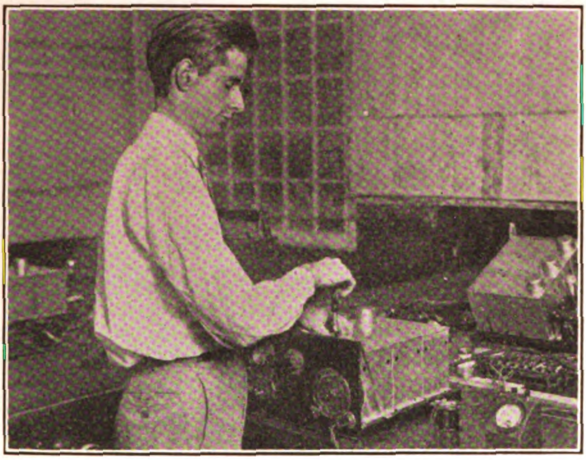

FIGURE 21

being maintained from the transformer primary windings, P_1, P_2 and P_3, through the 1 mf. by-pass condenser M_1, M_2 and M_3 to "—F" terminals of the tubes.

The neutralizing condenser used in these receivers is of a simple design, as shown in Figure 22. A spring-type hexagonal

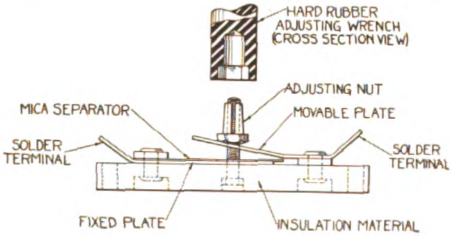

FIGURE 22

nut operates to change the position of a flat spring plate with respect to a similar stationary plate, when this nut is turned with a hard-rubber socket wrench as shown in Figure 23. The operator uses a radio headset, plugged into the output of the second

audio tube, to determine when the point of balance has been reached.

Following the alignment and neutralizing operations, a calibration curve of each receiver is hand-drawn from five points

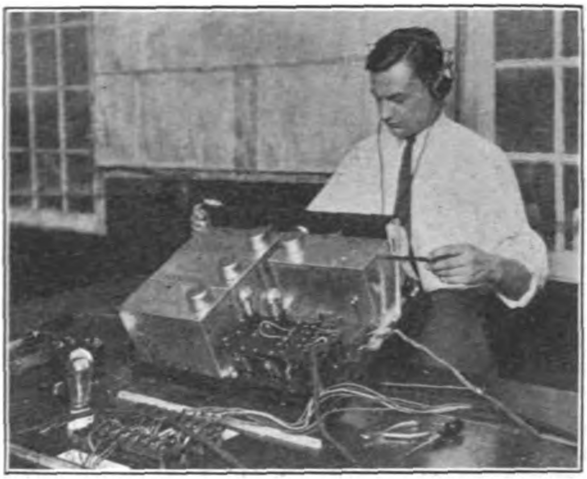

FIGURE 23

taken on the right hand station selector with the aid of a wave meter. These points can be made very accurate, as this selector control operates the three condensers of the second, third and fourth tuning stages and is extremely sharp when the volume control is turned down. The accuracy of this calibration curve, therefore, is not affected by changes in antenna conditions nor by slight differences in tube capacity.

AUDIO AMPLIFIER SYSTEM: As previously stated, the audio system of this receiver is of the two-stage transformer coupled type, with the second audio stage designed for a power output tube, such as the UX-112.

The audio transformers are specially designed to give a flat voltage-amplification curve over the range of audio frequencies that are considered essential to good quality reproduction. The usual "second peak" in the amplification curve, previously mentioned in this paper, is removed by the use of a short-circuiting band of copper applied around the outside of the secondary winding.

The turns ratio of these transformers, combined with the action of the short-circuit band, give a resulting voltage amplifi-

cation for the transformers alone of approximately 3½ to 1 for the first audio stage and 2 to 1 for the second audio stage.

As shown in the circuit Figure 11, both stages of the audio system are connected to the loudspeaker output binding posts and output "phone" jack at all times, thereby including sufficient audio amplification to insure ample volume of loudspeaker signal without the common tendency to overload the detector tube.

The complete receiver chassis is a self-contained unit that is designed to slide into an opening in a radio cabinet, similar to a desk drawer, and to be held in place with two 5-16 inch diameter automobile type cap screws, threaded directly into the rear member of the steel chassis framework. In some cabinets, these two screws need be used only for shipping purposes, and removed when the receiver is installed, thereby allowing the chassis to pull out like a drawer for inserting tubes, etc.

The individual shield covers are fastened securely to this chassis framework and therefore are sufficiently rigid to serve as a good mechanical protection for the variable condensers and other radio-frequency apparatus.

It has been found that this type of protection is advisable in a receiver that operates more than one tuning condenser with a common control, as the shields prevent accidental bending of condenser plates or changing of other elements that enter into the accuracy of the tuning circuits.

In conclusion, it will be noted that this manufactured design of totally shielded Neutrodyne receiver follows closely the principles outlined by Professor Hazeltine and his associates, and incorporates several mechanical features designed to insure reliability of operation when simplified controls are employed.

NEW METHOD PERTAINING TO THE REDUCTION OF INTERFERENCE IN THE RECEPTION OF WIRELESS TELEGRAPHY AND TELEPHONY*

By

H. de Bellescize

(Neuilly, France)

I—Principles Under Consideration

The opinion of the great majority of the authorities relative to the possibility of reducing atmoshperic interference in radio telegraphy and telephony, it seems to us, is summed up to-day, as follows:

Good results can be obtained by employing the differences of direction existing between parasitic currents (static or strays), and signals. To a less degree, phase differences can also be used to secure selectivity at the input of the receiving set. However, in so far as the oscillations created within the receiving set are concerned, no method can equal the judicious use of resonance; in certain cases, however, the devices do not take into account the independence of the oscillations and are, therefore, necessarily doomed to failure.

Even though this last conclusion is, in our judgment, very pessimistic, the impossibility of causing strong discharges superimposed on a continuous oscillation to disappear without at the same time suppressing this oscillation for a more or less prolonged period, seems to us to be axiomatic.

But the accuracy or exactness of this axiom can well be nullified by the method and devices hereafter described. Our point of departure* has been the hypothesis that a moving part retarded by constant friction cannot obey sinusoidal impulses of slight amplitude, even though the sinusoidal forces co-exist with other forces of no matter what form or shape and even if they are sufficiently intense to overcome the effect of friction.

By constant friction is meant that case in which the ampli-

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*Differential device for the elimination of atmospheric disturbances by damping.

French Patent No. 587,625—December 28, 1923. 1st addition: July 22, 1924—Not granted as yet. 2nd addition: April 8,1925—Not granted as yet.

. 'he velocity of the moving part. Funda-
... motion, this friction maintains a constant
...d has a tendency to stop the moving part;
...me all the values included between plus F and
... ces to which the moving part is subjected are
. splacements which result from curves which take
...sed cycles, the ascending and descending branches
...not coincide (Figure 1). The width of the cycle is
...

... amiliar example, we can cite the angular motion of a
..., the axis of which swings on its pivot. Neglecting the
...ance, the equation of the motion is:

$$G = K\,\theta'' + D\theta + f \tag{1}$$

...presents the starting couple applied to the pendulum; $K\,\theta''$ ...e couple due to inertia; $D\theta$ the couple due to gravity or to the ...ring; f the opposing couple due to the friction of the pivot. During motion, f maintains the value of F and its sign is that of velocity θ; at rest, it can assume all values included between minus F and plus F, in such a manner as to maintain the equilibrium between the forces present during an interval of time which may or may not be infinitely small, the graph of the motion will, therefore, eventually have flat places such as *aa*, *bb* (Figure 2), even though the applied couple, G, varies continuously.

At the outset, it is evident that if during the course of one of these flat places, a small supplementary couple ΔG, less than F, is momentarily superposed on the main couple, the equilibrium will not necessarily be disturbed; ΔG will have no effect on this case.

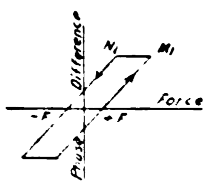

FIGURE 1

FIGURE 2

This idea can be extended. Let us suppose that for any reason whatsoever, which has disappeared, the moving part has passed from the position P_1 to the position P_2 and the equation of motion

$$G = K\,\theta_1'' + D\,\theta_1 + f_1 \tag{2}$$

which refers to the index curve (1), has changed to the equation

$$G = K\ \theta_2'' + D\ \theta + f_2 \tag{3}$$

which refers to the index curve (2).

The differential movement representing the free oscillation due to the cause which has disappeared is:

$$\theta = K\ (\theta_2 - \theta_1)'' + D\ (\theta_2 - \theta_1) + (f_2 - f_1) \tag{4}$$

As long as the velocities $_1'$ andθ_2' are not zero, the friction f_2 and f_1 remain constant in absolute value, and equation 4 represents the ordinary sinusoidal oscillation; the peaks of the curves do not lead to any change, even when the maxima or minima of curve (1) do not coincide in time with those of curve (2); this is deduced from the appearance in equation (4) of couples having a definite amplitude (2 F) and a short duration; therefore, their impulsive effect is negligible. This reasoning leads even further in the case of flat places. One of the two frictions remains constant, whereas the other varies progressively; the impulse now acquires a finite value susceptible of altering the free movement.

The expression for the impulses $\int_0^\infty (f_2 - f_1)\ d\ t$, shows that their influence will be proportionately greater as $(f_2 - f_1)$ *max.*—otherwise called F—is itself important in comparison with the elastic couple $D\ (\theta_2 - \theta_1)$, due to the free movement; and as the duration of the flat places becomes more considerable.

But, in order that there may be such a flat place, it is necessary, θ'' being now zero, that the expression

$$G = D\ \theta + f$$

be satisfied. That is to say, that the applied couple G balances the elastic couple $D\ \theta$ within a term included between $-F$ and $+F$.

Such states of equilibrium will occur more frequently and will be more prolonged when the couple G is less periodic and less regular (for aside, from resonance, G and $D\ \theta$ remain of the same order of magnitude) and when F becomes greater in proportion to the mean value of the couple G and $D\ \theta$. On the other hand, the instants when the presence of flat places interferes with the regularity of the free oscillation (4), depend upon the form of the couple applied at G. If this form is made non-periodic, there is a similar change on the variation in the free movement, which loses its sinusoidal character and its tendency to develop the resonance phenomena.

Since in such a system a free movement has a good probability of being rapidly destroyed, we are right in concluding that this system will not be susceptible to resonance under the action

of weak sinusoidal couples $\Delta G = A\,G_o \sin \omega t$ superposed upon the principle couple G. In fact, resonance signifies a movement produced by a present cause superposed on a movement freely damped due to previous causes.

Let us summarize the conclusions thus far:

In order that friction may stop the transmission of sinusoidal impulses (forces, couples, electromotive forces), superposed on other impulses of much greater amplitude which it is desired to allow to pass, it is necessary that: (1) the friction should be greater than the sinusoidal impulses and not too small in proportion to the others. (2) that these later impulses be as little periodic and as irregular as possible, which is precisely the case of atmospheric disturbances. To the properties, or rather the absence of those properties utilized heretofore for separating or picking out these interferences (absence of direction and regular phase), we add the absence of regularity and definite form. The new method, therefore, goes further into the mechanism of phenomena. Independently of the mechanical devices, it is possible to obtain hysteresis cycles by applying the properties of magnetic metals. The difference between the cycles in Figures 1 and 3 has been attributed** to the fact that as the molecule of the metal is subject to unequal frictions, its orientations require field variations of unequal values. Instead of being equal to unity, which would be the case with the horizontal flat places M_1N_1 of Figure 1, the mean permeability μ_o of the cycles of small extent is less than those cycles of greater extent.

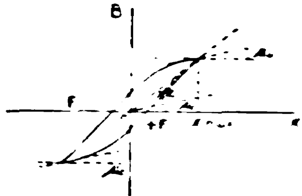

FIGURE 3

This progression in the friction is perhaps a very happy circumstance since it tends to add the width $-F+F$ of the cycle to its own length, which fact facilitates the formation of numerous flat places (or more accurately stated, regions corresponding to less permeability), in the curve of Figure 2.

**The energy losses in dielectrics. M. J. Granier. Bulletin of the Society of French Electricians. August 1923, No. 28, page 463.

Let us substitute for the idea of friction those which occur relative to the changes or variations of period and permeability, on the strength of what has been stated above. We have thought that a resonance circuit $L\ C$ (Figure 4 and following), in which the magnetic core acquires permeabilities, μ, greater than the initial permeability, μ_o, under the influence of intense irregular fields, is no longer likely to resonate under the action of weak sinusoidal electromotive forces.

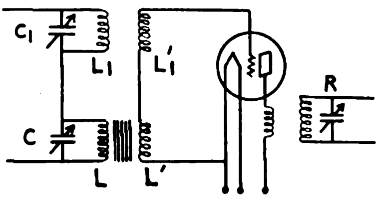

FIGURE 4

This principle defines the type of circuit intended to overcome the interference, and it indicates at the same time the main defect:

The signals being practically destroyed under the influence of the disturbances which is superposed upon them, recourse is made to a differential system. The resonant circuit, $L\ C$, having a magnetic core, will allow only the interference to pass; the other circuit L_1C_1 will transmit interference and signals. Superposition of these two outputs in opposite phases will leave the signals only remaining. The resonant circuit R is intended to eliminate the effect of inevitable differences of wave shape caused by parasitic currents from the differential resonant circuits.

The defect of the circuit is evident; as the permeability is a function of the field, each differential stage will stop only those disturbances whose amplitude is well defined or at least included between the rather restricted limits. This difficulty can be reduced, but it cannot be entirely overcome by the means under consideration. For example, one cannot hope to make the parasitic currents ineffective by the detuning eventually due to the variation of the permeability they provoke.

II—THE CONSTRUCTION OF A CIRCUIT

The first problem is so to construct a transformer that the ampere-turns which can be obtained from a receiving tube will appreciably modify the permeability of the magnetic circuit.

The frequency, nature of the metal, and manner of the construction. must be considered in this connection.

The frequency preferably should be fixed, which will permit adjustments (the super-heterodyne circuit is an example of this condition). Also, the frequency should be selected as low as possible in order to increase, at equal intensities, the number of windings of the coil L. The lower limit of the frequency depends, on the one hand, on the maxima time constant imposed on the resonant circuit R by the kind of service (telephony or telegraphy) and on the other hand, on the fact that the logarithmic decrement of this resonant circuit should be much less than that of the circuits $L\,C$, L_1C_1, from which come parasitic currents probably quite dissimilar in forms.

The metal should be so chosen that μ, the permeability which can be attained with the vacuum tube, will be as large as possible in comparison with the initial permeability μ_o.

Let n = the number of turns on the coil L.

K = its reactance in ohms, adapted to the plate resistance of the tube.

$s\,l$ = the cross-section and the length of the magnetic circuit, in centimeters.

L_o = the self-inductance for the permeability μ_o, in henrys.

ω = the pulsation.

i = the maximum current furnished by the plate circuit, in amperes.

Then, as a first approximation, we can write:

$$L_o = \frac{K}{\omega} = \frac{4\pi n^2 \mu_o s}{l} \times 10^{-9}$$

$$H_{max} = \frac{4\pi n i}{10\, l} \tag{5}$$

from which

$$H_{max} = 10^{-3}\, i \sqrt{40\pi \frac{K}{\mu_o\, \omega\, .\, s\, l}}$$

The suitability of the metal being determined by using the permeability curve in connection with the formula (5), the best procedure is to make various experiments and tests to determine the influence of the other factors; for instance, the form and period of the hysteresis cycle.

Formula (5) shows the necessity of reducing the cross-section and the length of the magnetic circuit. Although this reduction is limited by the necessity of maintaining the useful

flux which passes through the metal very great in proportion to that which follows other paths, it is possible to obtain dimensions much smaller than those of the ordinary transformers. Figure 5 represents in full size the profile of iron lamination used; almost all of the reluctance is in the branch s_1 which supports the coil, and whose cross-section is of the order of a square millimeter. Such a coil affords a very large number of windings.

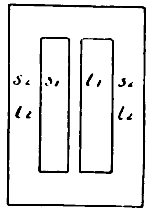

FIGURE 5

Once they have been decided upon, the transformers can be used in many different ways. The simplest, if not from the point of view of handling, at least from the point of view of the number of parts and of the necessary tubes, is that shown in Figure 6.

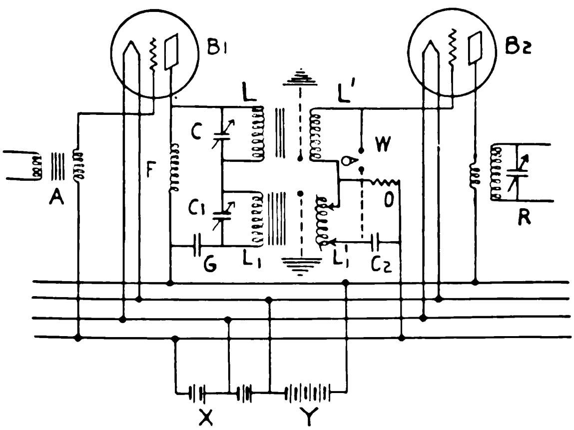

FIGURE 6

In the first place, experience shows the desirability of making the two opposing circuits as nearly identical as possible. With this in mind, we can equalize their own dampings and regulate the two by the same frequency as the rest of the circuit. It is understood that the value selected for the condenser C corresponds to the permeability transmitted to the iron of the coil LL' by the disturbances to be eliminated in that stage.

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Finally, it is theoretically possible to make the transformers $L\,L'$ such that their cores will maintain a sensible and constant reluctance between two quite extended limits. As a result, there will be an increase of the unduluations of the waves represented by the curves A_2A_3 (Figure 7), and consequently an increase in the ratio $O\,P_2/O\,P_1$.

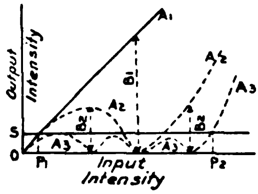

FIGURE 7

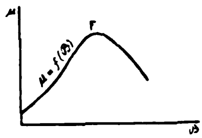

FIGURE 8

The magnetic circuit represented in Figure 5 has in series. two branche s cross-section and length s_1l_1 and s_2l_2 very unequal Calling R the total reluctance, $\mu_1\mu_2$ the permeabilities of the branches, $\mu=f(B)$ the equation of the curve represented in Figure 8, the flux, θ, can be written:

$$\Phi=\frac{4\pi n i}{R} \quad R=\frac{l_1}{\mu_1 s_1}+\frac{l_2}{\mu_2 s_2} \qquad \mu_1=f\left\{\frac{\Phi}{s_1}\right\} \mu_2=f\left\{\frac{\Phi}{s_2}\right\}$$

Taking the flux as the independent variable, we deduce $\mu_1\mu_2\,R=i$. The relation between i and R will be valid up to the maximum current value furnished by the tube.

By revising the data s_2l_2, it is possible to conclude by successive approximations that (the branch s_2 working in the ascending portion of the characteristic, whereas the other has gone beyond the elbow F), the increase of reluctance of one compensates within certain limits the decrease of reluctance of the other.

A complete circuit is schematically shown in Figure 9.

$A\,B$ represents the tuned input to the circuit.

Q_1 is a first detector, D_1 is the heterodyne transforming the high frequency to another, chosen once for all to achieve the desired result. E_1E_2 are resonant circuits much more damped than the resonant circuit R placed after the differential stages. The latter, according to the description in Figure 6, are separated by an amplifier J to facilitate the operation of the second differential stage intended to operate on disturbances of less intenisty. The heterodyne D_2 serves for telegraphic reception if the intermediate frequency is chosen in the inaudible range. The rest of the circuit offers nothing unusual.

The adjustment of the intermediate frequency is made once for all, the only adjustment which the operator has to make is that of the rheostat *H* which assures the necessary sensitiveness in the working of the iron.

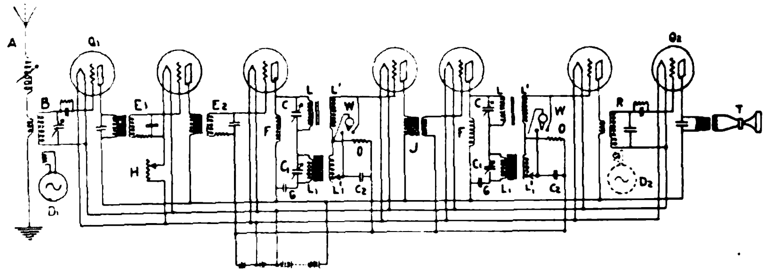

FIGURE 9

III—ADJUSTMENTS AND TESTS

The preliminary study of the transformers *LL'* consists chiefly in making certain that a strong emission causes an appreciable change in the permeability of the iron. One should use, for example, for this purpose the circuit shown in Figure 10, in in which the phase variation and the amplitude changes corresponding to the different intensities read by the aid of a thermocouple *S*, are measured by an artificial line *M* half a wave-length long terminated without reflection in a resistance *J*. The current is supplied by a heterodyne *H* of which the frequency is that chosen for reception. For each value of the intensity, the sliding contacts *P* and *Q*, the first of which measures the phase variations, and the second the amplitudes, are adjusted so as to obtain the complete extinction of the signal. The currents that are too weak are detected by a shunted telephone receiver, taking as a basis of comparison the lowest reading of the thermocouple *S*. For wave-lengths of the order of 7,000 meters, we have obtained marked phase variations with many samples of steel, and when the plate current did not exceed one milliampere.

Before proceeding to the damped disturbances, it is convenient to study the adjustment of the differential stages with the aid of of continuous local signal of variable intensity and of a wave-length equal to that for which the receiving set is designed. We proceed one stage at a time, the others comprising but one transformer by operating the switch *W* (Figure 9). With regard to the differential stage under investigation, we must first tune the resonant circuit *L C* for a faint signal; then we find the point of

extinction of this signal by the operation of condenser C_1 and the secondary L_1'. If the circuit is correct, the adjustment thus found for C_1 should very nearly make the circuit L_1C_1 resonate, which is not to be touched upon in the following. Next, increasing the intensity of the signal, we can determine the values of $C_1'L_1'$, for which the extinctions are the best. The relation existing between these two parameters will be much more difficult to find by means of irregular disturbances.

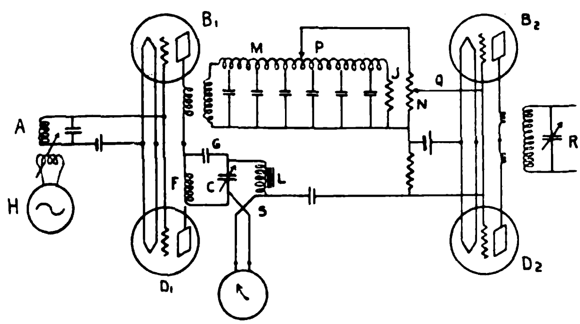

FIGURE 10

It is next easy to adjust simultaneously the two stages in such a manner as to extinguish two different intensities of emissions and to reproduce the curve A_3 of Figure 8. The stage on the left will first be adjusted so as to eliminate a very intense signal; and next the stage on the right to reduce the first undulation of curve A_2 which will appear clearly in continuously reducing the coupling with the local oscillator.

The adjustment obtained in this manner is capable of eliminating the damped disturbances produced, for example, by a musical tune acting on the antenna. With two protective stages, the reading of a signal remains clear under the action of artificial parasitic currents which, in the absence of this device, would necessitate the use of a power 80 times as great. One is especially struck by the impression of the continuity of the signal; this continuity is maintained when one modifies the frequency of the buzzer between the very extended limits, for example, from 50 to 1,000 impulses per second; or when one progressively increases its action upon the antenna up to the value OP_2 (Figure 8), for which the apparatus is adjusted. The presence of the disturbances does not modify in an appreciable manner the intensity of the signal.

Therefore one is led to believe that, no matter what the

continuity of the atmospheric disturbances, signals will pass through them all right just as if the power of the sending station had been effectively increased; the few tests that have been performed up to this date are encouraging, and the storms of the coming summer will suffice to determine this point.

These various results have been obtained for telegraphic signals, received with two heterodynes. In telephony, the adjustments are very much more delicate and the tests heretofore have been less successful. The obstacles encountered are due, it seems, to two principal causes. To improve the tuning, there is a tendency to exaggerate the constant time of the last tuned circuit, which can resonate unequally (and consequently cannot function correctly) even though the words and the music seem properly rendered. On the other hand, the quality of the signal requires a very weak modulation of the carrier wave, in accordance with the well-known expression:

$$S(1+a \sin \Omega t). \quad \sin \omega t$$

we have to operate on a signal of reduced power ($S.\, a \sin \Omega t\, .\, \sin \omega t$) which must be picked out from atmospheric disturbances despite the permanent disturbance of another oscillation ($S \sin \omega t$) which is much more intense.

Therefore, we shall see this problem adds further and new difficulties. Let us add that in the present case there is, without doubt, an excellent solution.

The influence of the disturbances originating from signals superposed on that to be received constitutes the weak point of the present device, and this fact has been examined with care. The working process consists in superposing on a signal of constant intensity and wave-lengths a disturbance (fog) of variable intensity and wave-length, the two signals being furnished by two sending stations. The intensities are measured by means of the shunted telephone receiver, before and after the differential stages. It includes the rheostat H (Figure 9), which assures the proper sensitiveness; these stages are adjusted, as it has been stated above, in order to assure the best elimination of the parasitic currents. The measurement of the wave-lengths in the intermediate frequency part of the receiving circuit is accomplished by the extinction of the musical note due to the interference of the calibrating heterodyne D_2. Note (1) the wave-lengths $\lambda_B\, \lambda_s$ of the interference and of the signal; (2) the relation $I_B\, I_s$ of their intensities in the circuit preceding the differential circuits; (3) the weakening I_1/I_2 of the signal dis-

turbance; I_1 being the intensity with the disturbance, and I_2 that without disturbance.

There results a family of curves. The most interesting results are those of which Figure 11 gives an example; the wave-lengths of the disturbance are plotted as abscissa, the curve (X) gives the relative intensities I_B/I_s for which the disturbance begins to weaken the signal; the curve (B) the realtive intensities for which the weakening of the signal is a maximum, the values of these reductions being written in parenthesis. For more energetic disturbances, the intensity of the signal increases rapidly, and it may even exceed that observed in the absence of the disturbance.

This example relates to a differential circuit adjusted once and for all in such a manner as to eliminate sustained oscillations of the same frequency as the signal and of intensities from 10 to 80 times greater, which conditions correspond very well to the attenuation of the parastitic currents, having given the respective constant time of the resonant circuits placed before and after the differential stages This example is not absolute; the data are likely to vary with the adjustment of the apparatus. Nevertheless, one can deduce some observations.

The selective power of the circuits following the differential stages is limited to a certain maximum, about 10 in the example stated above; this however is not important in respect to the eliminations of the waves close to the signal in frequency, nor for the waves very different in frequency against which one can be protected by the aid of tuned circuits at the input, but there do exist on either side of λ_s, two narrow frequency bands inside of which the selectivity of the receiving set is practically diminished. We note this fact without having met any case where it has had any detrimental effect.

As a counter-measure, the circuit permits the elimination of certain disturbances against which we would otherwise be absolutely unable to cope. When, for example, a stage is very closely adjusted so as to extinguish completely a powerful disturbance which has nearly the same wave-length as the signal, the latter can still be received in the form of beats, marking, without doubt, its phase variations in respect to the disturbances; when there is coincidence or opposition, the signal being confused with the disturbance is stopped at the same time as the disturbance by the differential stage; in quadrature, on the contrary, it passes freely. The mean reduction of signal intensity is now about equal to 2. One therefore foresees the value of a

stage in which the parts can be adjusted by the operator, and especially intended for the elimination of the disturbances.

The weakening of a signal by a disturbance would have no great importance if in no case the value 2 were exceeded; this is what one would hope for. Figure 11 shows that unfortunately this is not the case. It can be seen, although not as yet explained,

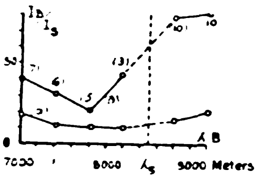

FIGURE 11

that the maxima in weakening seem to increase as one departs from λ_s. Besides, the curves *I* and *II* are not symmetrical in respect to this wave-length: which is caused without doubt by the fact that the circuits LC and $L_1 C_1$ not being identical at every point, a good opposition demands that one of them should be slightly out of tune.

SUMMARY: The usefulness of directional reception and of resonant circuit selectivity in reducing the effect of atmospheric disturbances of reception is first considered.

Assuming that sinusoidal forces coexist in a system with much larger impulses, it is shown that the sinusoidal forces will not pass through systems having internal frictional losses under certain definite conditions. The analogy between mechanical frictional systems and magnetic hysteretic systems is utilized in devising differential circuit arrangements whereby strong impulses, passing through two opposing circuits of controllable hysteric damping, are ultimately balanced out, whereas smaller sinusoidal currents are delivered at the output of the system. The application to radio reception is described in detail.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued January 5, 1926—March 2, 1926

By
JOHN B. BRADY

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,568,065—ROSS GUNN, filed June 9, 1923, issued January 5, 1926, resident of Dayton, Ohio.
CONSTANT FREQUENCY SOURCE, wherein a plurality of electron tubes are arranged in a common control circuit with impedances so disposed therein that the frequency of the generated oscillations is not dependent upon the plate voltage or filament currents in the system.

1,568,172—F. S. McCULLOUGH, filed May 6, 1925, issued January 5, 1926, resident of Wilkinsburg, Pennsylvania.
THERMIONIC TUBE, in which an auxiliary heater is provided within the tube for raising the cathode element to an electron emitting temperature.

1,568,274—D. GRIMES, filed May 18, 1922, issued January 5, 1926, assigned to Grimes Radio Engineering Company, Incorporated.
CONDENSER where a set of stationary and movable plates is varied in position longitudinally with respect to each other for varying the effective capacity of the condenser.

1,568,632—L. Q. SLOCUMB, of Ferguson, Missouri, filed January 2, 1924, issued January 5, 1926.
RADIO RECEIVING APPARATUS having a single control for variation of both capacity and inductance in the tuning circuit of the receiver.

1,568,701—J. C. WARNER, filed March 5, 1925, issued January 5, 1926, assigned to General Electric Company of New York.
ELECTRON DISCHARGE DEVICE, in which a tube having two grids interposed between the anode and cathode is provided with a coupling between the grid circuits for facilitating the production of oscillations.

1,568,827—W. H. GERNS, filed June 21, 1924, issued January 5, 1926, assigned to Brandes Laboratories, Incorporated, of Newark, New Jersey.
APPARATUS FOR TESTING TELEPHONE RECEIVERS, for the production of telephone receivers or loud speaker units and the inspection of such devices for the rejection of defective units without loss of time on the part of the operator.

1,568,918—E. PFIFFNER, of Frybourg, Switzerland, filed March 19, 1923, issued January 5, 1926.
ELECTRIC CONDENSER, constructed of dielectric material having metal coatings thereon which are spacially related for building up a condenser structure.

1,568,939—E. E. CLEMENT, filed August 14, 1922, issued January 5, 1926, assigned to Edward F. Colladay, Washington, D. C.
SYSTEM FOR RADIO BROADCAST DISTRIBUTION, wherein a central station is provided for controlling the operation of a plurality of receivers in a community adjacent a broadcasting station.

1,568,979—V. O. KNUDSEN, filed September 3, 1921, issued January 12, 1926, assigned to Western Electric Company, Incorporated. New York.
OSCILLATION GENERATOR, where the input and output circuits

* Received by the Editor, March 11, 1926.

are controlled through a common switching system for simultaneously varying the constants of the circuits.

1,569,095—C. A. LAISE, filed November 21, 1923, issued January 12, 1926, assigned to Electron Relay Company, of Ohio.
BODY OF HIGH ELECTRON AND LIGHT EMISSION AND PROCESS OF MAKING THE SAME, for use as electron emitting elements for electron tubes where tungsten, thorium and vanadium having the crystals thereof interspersed with grains of difficultily reducible refractory oxides, is provided.

1,569,211—E. W. SPENCER, of Hemple, Missouri, filed May 16, 1924, issued January 12, 1926.
VARIABLE CONDENSER, where the movable plates are adjusted longitudinally with respect to the stationary plates.

1,569,325—A. LEIB, filed August 8, 1922, issued January 12, 1926, assigned to Gesselschaft fur Drahtlose Telegraphie m.b.h. of Berlin, Germany.
RADIO DIRECTION FINDER for shipboard installation where the frame of the direction finder coil is supported in a rockable bearing with a counter-weight for maintaining the direction finder coil substantially in one plane at all times.

1,569,353—Q. A. BRACKETT, filed August 5, 1919, issued January 12, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO RECEIVING SYSTEM, employing a construction of electron discharge tube in which the incoming signal receiving circuit is arranged to directly influence the electron discharge within the tube.

1,569,354—L. T. CARL, et al of Winona, Mississippi, filed January 21, 1924, issued January 12, 1926.
RADIO RECEIVING SET having parts arranged in such close relationship that bus wires are eliminated.

1,569,384—R. E. MARBURY, filed August 3, 1921, issued January 12, 1926, assigned to Westinghouse Electric & Manufacturing Company of Pennsylvania.
CONDENSER of stacked construction where the plates are secured under pressure by means of bowed spring clamps.

1,569,395—R. E. MARBURY, filed August 18, 1921, issued January 12, 1926, assigned to Westinghouse Electric & Manufacturing Company, of Pennsylvania.
CONDENSER CASING for enclosing a stacked condenser unit where telescopic parts are provided and welded together over the condenser stack.

1,569,446—T. E. ARUNDEL, filed March 12, 1925, issued January 12, 1926, assigned to G. D. Shipherd and W. H. Metcalf, of Omaha, Nebraska, 37½ percent and 25 percent respectively.
RADIO RECEPTION APPARATUS, including a crystal detector having a plurality of points engaged with the crystal surface forming the rectifier element in the receiving set.

1,569,630—T. R. GRIFFITH, filed December 12, 1923, issued January 12, 1926, assigned Western Electric Company, Incorporated, of New York.
ELECTRON DISCHARGE DEVICE of high power construction where the electrodes are carried on metallic rods spaced apart by an insulating block.

1,569,766—D. H. MOSS, filed February 27, 1925, issued January 12, 1926, assigned to Brandes Laboratories, Incorporated, of Newark, New Jersey.
TERMINAL FOR TELEPHONE RECEIVERS, where a locked stud is provided in the casing of the telephone receiver or loud speaker unit for establishing connection between the bobbins within the unit and the exterior of the unit.

1,569,835—E. W. KELLOGG, filed January 30, 1925, issued January 12, 1926, assigned to General Electric Company of New York.
RADIO TRANSMISSION SYSTEM, arranged with a distributed load whereby current may be supplied from a transmission line at a plurality of points along its length without producing any refractions.

1,570,261—A. J. KLONECK, of New York, N. Y., filed May 12, 1921, issued January 19, 1926.
SIMULTANEOUS SENDING AND RECEIVING SYSTEM, wherein switching means are provided for transferring the circuits of the apparatus to various types of antennae systems.

1,570,265—K. A. LEBBINK, filed July 5, 1923, issued January 19, 1926, assigned to Naamlooze Vennootschap Philips' Gloeilampenfabriken, of Eindhoven, Netherlands.
ELECTRODE FOR DISCHARGE TUBES, where successive turns of coiled electrode are supported in a slotted bar member, the slots of which are substantially closed for anchoring the turns therein.

1,570,444—A. MAVROGENIS, of Milwaukee, Wisconsin, filed December 26, 1923, issued January 19, 1926.
RADIO APPARATUS, in which an electron tube having a multiplicity of electrodes is connected in a circuit for simultaneous rectification of incoming signaling energy. The tube operates from the alternating current lighting source.

1,570,499—J. F. KEANE, of Bridgeport, Connecticut, filed February 28, 1924, issued January 19, 1926.
RADIO BATTERY CHARGING SWITCH MEANS for A and B batteries wherein a convenient circuit is provided for switching the battery units from a position of charge to a position for power consumption.

1,570,755—O. H. LOVNES, filed August 22, 1923, issued January 26, 1926, assigned to American Telephone & Telegraph Company of New York.
RADIO RINGING SYSTEM, wherein circuits are provided for interrupting a radio frequency at a ringing frequency for operating a vibrating polar relay at a radio receiver for actuating a call device.

1,570,959—J. O. GARGAN, filed January 16, 1924, issued January 26, 1926, assigned to Western Electric Company, Incorporated, of New York.
TUBE MOUNTING for high power operation where the tube is surrounded by a water jacket and cooling circulating water supplied therearound.

Design 69,280—DAVID H. MOSS, filed August 21, 1925, issued January 19, 1926. Assigned to Brandes Laboratories, Incorporated, of Newark, New Jersey.
CASING FOR A PHONOGRAPH LOUD SPEAKER UNIT, which may be mounted directly upon the table of a phonograph adjacent the record support and attached to the tone arm for utilizing the phonograph as a radio reproducer.

1,571,011—B. W. KENDALL, filed December 3, 1920, issued January 26, 1926. Assigned to Western Elecrric Company, Incorporated, of New York.
SECRET SIGNALING, where a carrier wave mouulated in accordance with speech is radiated and an inverted speech frequency band superimposed thereupon and properly distributed at the receiver.

1,571,020—W. D. McGOWAN, of Jersey City, New Jersey, filed September 16, 1922, issued January 26, 1926.
CRYSTAL DETECTOR FOR RADIO TELEPHONY AND TELEGRAPHY, in which a rectifier element is supported between bristles which extend inwardly from opposite ends of a tube.

1,571,050—W. H. GERNS, filed April 29, 1925, issued January 26, 1926. Assigned to Brandes Laboratories, Incorporated, Newark, New Jersey.
ELECTROMAGNETIC DRIVING APPARATUS for operation of cone speakers or loud speakers, where a push-pull sound reproducer unit is provided for actuating a common armature member for the production of sound.

1,571,257—H. M. FREEMAN, filed August 18, 1921, issued February 2, 1926. Assigned to Westinghouse Electric & Manufacturing Company of Pennsylvania.
GRID LEAK formed by inside and outside metallic film coatings which are deposited upon the walls of an electron tube.

1,571,278—L. KUHN, filed August 26, 1921, issued February 2, 1926. Assigned to Westinghouse Electric & Manufacturing Company of Pennsylvania.
CONNECTION FOR PRODUCING OSCILLATIONS WITH VACUUM TUBES, where the input and output circuits of a tube each contain adjusting devices which may be simultaneously changed for controlling the oscillations.

1,571,370—G. H. CLARK, filed March 3, 1921, issued February 2, 1926. Assigned to Radio Corporation of America of Delaware.
VARIABLE CONDENSER, wherein the rotor plates of the condenser may be moved longitudinally with respect to the stator plates at the same time that rotative motion of the plates may be obtained.

1,571,371—G. H. CLARK, filed March 17, 1921, issued February 2, 1926. Assigned to Radio Corporation of America of Delaware.
RADIO SIGNALING APPARATUS, where a continuous wave transmitter is provided with an absorbing circuit for diverting portions of the signaling energy during non-signaling periods with means for super-imposing emf. of low frequency on the main emf. in the antenna circuit for the production of signals.

1,571,373—N. E. DAVIS, filed December 3, 1921, issued February 2, 1926. Assigned to Radio Corporation of America of Delaware.
RADIO TRANSMITTING APPARATUS, in which telegraphic signals are radiated by virtue of a key circuit which effectively shunts a portion of an inductance which is coupled to the antenna circuit while the radiated frequency remains constant.

1,571,463—V. K. ZWORYKIN, filed July 19, 1921, issued February 2, 1926. Assigned to Westinghouse Electric & Manufacturing Company of Pennsylvania.
OSCILLATION GENERATOR SYSTEM, in which a plurality of electrodes are arranged in an evacuated envelope in a position where the electrodes extend along radial lines from the center of the tube. Excitation of the tube may be obtained from single phase or polyphase sources of energy for the generation of high frequency current.

1,571,499—J. H. THOMPSON, of Hollidays Cove, West Virginia, filed November 17, 1924, issued February 2, 1926.
ELECTRON DISCHARGE DEVICE, wherein a pair of anodes and a pair of separate filament electrodes are arranged in the tube with separate terminals brought out from the tube base.

1,571,501—VANDEVENTER, filed June 25, 1923, issued February 2, 1926. Assigned to Dubilier Condenser & Radio Corporation of New York, N. Y.
ELECTRICAL CONDENSER, consisting of annular outwardly conductive and insulated plates which are secured together by a lead rivet passing through the center thereof.

1,571,512—W. DUBILIER, filed January 31, 1924, issued February 2, 1926. Assigned to Dubilier Condenser & Radio Corporation of New York, N. Y.
ELECTRICAL CONDENSER of the stacked type where the terminals which provide connections for the opposite plates of the condenser also serve to exert pressure on the stack.

1,571,900—F. L. LORD, filed March 12, 1925, issued February 2, 1926. Assigned one-half to Harry J. Lucke, of New York, N. Y.
TUNED RADIO FREQUENCY RECEIVING SYSTEM, where the intervalve transformers have means for varying the capacity reactance therein and for varying the self-inductance of each primary winding and the mutual inductance of each transformer. The circuit is arranged for eliminating objectionable feedback oscillations.

1,571,907—T. G. McCLANAHAN, of Seattle, Washington, filed March 29, 1924, issued February 2, 1926.
DETECTOR of the crystal type where the entire rectifier is housed within an insulated body structure which may be readily mounted within the radio receiver.

1,571,948—W. G. HOUSEKEEPER, filed June 9, 1922, issued February 9, 1926. Assigned to Western Electric Company, Incorporated, of New York.

ELECTRON DISCHARGE DEVICE, in which connections are provided for passing a cooling fluid around the anode of a high power tube.

1,572,204—J. H. HAMMOND, JR., of Gloucester, Massachusetts, filed August 20, 1917, issued February 9, 1926.
MEANS FOR LIMITING THE EFFECT OF STATIC OR OTHER DISTURBANCES IN RADIO TELEGRAPHY, which consists of a magnetizing element placed in the grid circuit of an electron tube and arranged for preventing excessive currents due to static from detrimentally effecting the receiving circuit.

1,572,244—E. B. NOWOSIELSKI, filed April 12, 1922, issued February 9, 1926. Assigned to Splitdorf Electrical Company, of Newark, New Jersey.
CONDENSER, which is substantially enclosed by insulating material which wholly clamps around the condenser stack.

1,572,504—H. PERLESZ, filed October 22, 1924, issued February 9, 1926. Assigned to Zenith Radio Corporation of Illinois.
ELECTROSTATIC CONDENSER of variable rotary plate construction, where the stator plates are mounted in a casting which also provides bearings for the shaft which carries the rotary plates.

1,572,530—W. F. HENDRY, filed December 28, 1918, issued February 9, 1926. Assigned to Western Electric Company of New York.
VACUUM TUBE, in which the terminals of the electron tube are supported in a plate of insulating material which is gripped in a metallic shell which surrounds the base of a vacuum tube.

1,572,604—C. HORTON, filed September 3, 1924, issued February 9, 1926. Assigned to Dubilier Condenser & Radio Corporation, New York.
RADIO CONDENSER of the stacked type where the stack may be secured in various positions by means of bent strip members which engage the terminals of the condenser and form supports therefor.

1,572,721—W. G. HOUSEKEEPER, filed December 11, 1920, issued February 9, 1926. Assigned to Western Electric Company, Incorporated, New York.
VACUUM TUBE, in which the elements are mounted from an insulated block by resilient members for taking up mechanical vibration to which the electrodes might otherwise be subjected.

1,572,726—M. J. KELLY, filed August 31, 1922, issued February 9, 1926. Assigned to Western Electric Company, Incorporated, of New York.
ELECTRON DISCHARGE DEVICE, where the cathode is prevented from vibrating by means of a pair of insulating members which grip the cathode intermediate its ends to prevent vibration thereof.

1,572,773—ALFRED CROSSLEY, of Washington, D. C., filed November 24, 1924, issued February 9, 1926. Assigned to Wired Radio, Incorporated, of New York, a corporation of Delaware.
PIEZO ELECTRIC CRYSTAL APPARATUS, where a piezo electric crystal for controlling the frequency of a transmitting station is mounted in such manner that the mechanical vibrations thereof may be utilized to control the frequency of an electron tube oscillator.

1,572,877—M. C. BATSEL, filed October 4, 1922, issued February 16, 1926. Assigned to Westinghouse Electric & Manufacturing Company of Pennsylvania.
RADIO RECEIVING APPARATUS, in which the electron tube support within the receiver is resiliently mounted from opposite ends and the movement of the electron tube socket support maintained within given lengths.

1,572,882—E. W. BREISCH, filed November 9, 1918, issued February 16, 1926. Assigned to Westinghouse Electric & Manufacturing Company of Pennsylvania.
HOT CATHODE APPARATUS, where the cathode is maintained in an electron emitting condition by energy which is supplied at separated points of the cathode and the relative amount of current passing through the cathode accurately governed.

1,572,897—R. E. MARBURY, filed December 14, 1920, issued February 16, 1926, Assigned to Westinghouse Electric & Manufacturing Company, of Pennsylvania.
VARIABLE CONDENSER, in which corrugated spacer washers are interposed between adjacent condenser plates for supporting the plates in fixed relationship.

1,572,910—A. L. WILSON, filed April 21, 1921, issued February 16, 1926. Assigned to Westinghouse Electric & Manufacturing Company of Pennsylvania.
THERMIONIC DEVICE, in which one electrode of the electron tube is embedded within the wall of the electron tube.

1,573,171—F. R. KRONFOTH, of Amsterdam, New York, filed February 12, 1925, issued February 16, 1926.
RADIO ANTENNA, having means for compensating for the contraction and expansion of the antenna under conditions of variable temperature.

1,573,303—E. H. COLPITTS, filed November 2, 1920, issued February 16, 1926. Assigned to Western Electric Company, Incorporated, of New York.
CARRIER WAVE TRANSMISSION, by which a plurality of messages are transmitted simultaneously and selectivity separated by tuned circuits at a receiver.

1,573,317—W. H. HOUSEKEEPER, filed June 2, 1922, issued February 16, 1926. Assigned to Western Electric Company, Incorporated, of New York.
MANUFACTURE OF VACUUM TUBES, where the tubes are sealed off while a space current is supplied to the tube circuits for releasing occluded gases from the electrodes of the tubes.

1,573,367—H. DEF. ARNOLD and J. P. MINTON, filed November 12, 1917, issued February 16, 1926. Assigned to Western Electric Company, Incorporated, of New York, N. Y.
METHOD OF GENERATING AN ALTERNATING CURRENT OF VARIABLE FREQUENCY, in which an oscillator has its constants cylclally and continuously varied for producing a variable frequency.

1,573,374—P. A. CHAMBERLAIN, filed July 2, 1924, issued February 16, 1926. Assigned to Electrical Dealers Supply House, Incorporated, of Chicago, Illinois.
RADIO CONDENSER, including a plurality of condenser units which are separated one from another by an intervening plate supported from the frame which carries the condenser units.

1,573,789—M. OSNOS, filed July 11, 1923, issued February 16, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie m.b.h. Hallesches, of Germany.
TRANSMITTING ARRANGEMENT FOR RADIO SIGNALING, including a static frequency changer which is modulated in accordance with speech or telegraphic signals for radiating signaling energy.

1,573,801—R. BOWN, filed October 5, 1923, issued February 23, 1926. Assigned to American Telephone & Telegraph Company of New York, N. Y.
TROUBLE ALARM SYSTEM FOR RADIO RECEIVING SETS, where local signal may be transmitted periodically to a receiving set for determining the operating condition of the receiver.

1,573,852—W. J. O'LEARY, of Montreal, Quebec, Canada, filed April 5, 1920, issued February 23, 1926.
HIGH FREQUENCY OSCILLATING DEVICE, where a condenser in the form of a primary and secondary coil is provided. The condenser is built up of primary and secondary elements in sheet formation spirally wound.

1,573,948—D. M. TERRY, filed November 21, 1925, issued February 23, 1926. Assigned to Western Electric Company, Incorporated, of New York, N. Y.
MEANS FOR PRODUCING OSCILLATIONS of constant frequency with means for stabilizing the oscillator circuit for rendering the oscillator insensitive to impedance changes.

1,573,983—R. C. MATHES, filed August 8, 1923, issued February 23, 1926. Assigned to Western Electric Company, Incorporated, of New, York, N.Y. SECRET SIGNALING, where a plurality of transmission paths are arranged with a distributor and a storage element for simultaneously impressing on the paths successively produced message current components which are unscrambled at the receiver.

1,573,984—J. P. MAXFIELD, filed June 9, 1922, issued February 23, 1926. Assigned Western Electric Company, Incorporated, of New York, N.Y. RADIO BROADCASTING EQUIPMENT, where a distortionless air damped transmitter having a diaphragm whose natural period of vibration is not substantially less than 400 periods per second. The patent shows circuits for monitoring the audio frequency input power of a radio transmitter.

1,574,209—P. M. SMITH, filed June 4, 1924, issued February 23, 1926. Assigned to United States Tool Company, Incorporated, Newark, New Jersey.
STATOR FOR VARIABLE CONDENSERS, where the stator plates are supported on screw-threaded posts with tubular insulated members supporting the posts.

1,574,268—B. R. WEBSTER, filed April 28, 1924, issued February 23, 1926. Assigned to Reliance Die & Stamping Company, of Chicago, Illinois.
ELECTRICAL CONDENSER, in which an end thrust bearing is provided for supporting the rotor plates of a condenser in desired spacial relationship with respect to the stator plates.

1,574,424—H. A. HATCH, filed October 16, 1920, issued February 23, 1926. Assigned to Splitdorf Electrical Co., of Newark, New Jersey.
CONDENSER, in which alternate layers of mica and conductive plates are secured under pressure in a stack by means of clamping terminals which exert pressure on the cover plate of the condenser stack.

1,574,472—H. F. Elliott, filed June 22, 1921, issued February 23, 1926. Assigned to Federal Telegraph Company, of California.
RADIO FREQUENCY ARC, where means are provided for adjusting the arc electrodes so as to produce optimum value as regards the arc output. Mechanical means are provided responsive to vibrations beyond definite limits of the voltage drop across the electrodes for moving the electrodes relative to each other.

1,574,473—H. F. ELLIOTT and J. ARTHUR MILLER, filed January 9, 1922, issued February 23, 1926. Assigned to Federal Telegraph Company, of California.
RADIO FREQUENCY SYSTEM, in which the frequency of an arc transmission system is maintained constant by providing a plurality of parallel paths for the current in the antenna circuit with means for insuring that there be no cross currents in the parallel paths.

1,574,715—C. E. WARNER, filed May 18, 1925, issued February 23, 1926. Assigned to Benjamin Electric Manufacturing Company, of Illinois.
CONDENSER, where the rotor shaft which supports the rotor plates of a variable condenser is supported in a thrust bearing arranged in the frame from which the stator plates are supported.

1,575,013—J. SLEPIAN, filed August 18, 1921, issued March 2, 1926. Assigned to Westinghouse Electric & Manufacturing Company of Pennsylvania.
RADIO INTERFERENCE PREVENTION means for application to flue-gas treaters or electromagnetic precipitating devices. A flue-gas treater is provided with a circuit for preventing high frequency radiation from the treater to prevent interference with local radio operations.

1,575,044—W. DUBILIER, filed May 24, 1921, issued March 2, 1926. Assigned to Dubilier Condenser & Radio Corporation, of New York, N. Y.
ELECTRICAL CONDENSER, where the plates of a condenser stack are maintained under pressure by a clamping device which fits within the condenser casing.

1,575,045—W. DUBILIER, filed February 14, 1924, issued March 2, 1926. Assigned to Dubilier Condenser & Radio Corporation, of New York, N.Y.
ELECTRICAL CONDENSER of the stacked type wherein a clamping device is provided for exerting pressure on the stack and for maintaining the stack in such position that electrical connections may be made with the terminals of the condenser independently of the clamp.

1,575,067—L. B. LAMBERT, filed February 17, 1925, issued March 2, 1926, resident of Wichita, Kansas.
FUNCTIONING PARTS OF MINERAL TYPE DETECTORS, where the contact member for a crystal detector is provided with a weight for maintaining the contact member in position with respect to the crystal.

1,575,340—C. W. HOUGH, filed February 25, 1924, issued March 2, 1926. Assigned to Wired Radio, Incorporated, of New York, N.Y., a corporation of Delaware.
WIRED RADIO RECEIVING APPARATUS, designed for protection of the receiving circuits against breakdown arising from the destructive effects of the power lighting circuit which extends into the receiver and over which the wired radio programs are broadcast. This patent covers the type of wired radio receiver installed in the wired radio installation on Staten Island.

1,560,505—ROBERT D. DUNCAN, JR., filed May 19, 1925, issued November 3, 1925. Assigned to Wired Radio, Incorporated, of New York, N.Y., a corporation of Delaware.
METHOD OF CARRIER FREQUENCY SUPPRESSION, wherein a polyphase source of high frequency current is employed for transmission of signals and radiation secured by unbalancing one of the phases.

PROCEEDINGS OF
The Institute of Radio Engineers

Volume 14 JUNE, 1926 Number 3

CONTENTS

GENERAL INFORMATION

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings and at the Sections in the several cities listed on the following page.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership.

Subscriptions to the Proceedings are received from non-members at the rate of $1.50 per copy or $9.00 per year. To foreign countries the rates are $1.60 per copy or $9.60 per year. A discount of 25 per cent is allowed to libraries and booksellers.

It is understood that the statements and opinions given in the Proceedings are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

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INSTITUTE ACTIVITIES

New Members and Transfers

At the April Board meeting 185 Associates and 14 Juniors were elected. The following Associates were transferred to Member grade: Paul F. Johnson, Francis M. Ryan, Harry B. Coxhead, Raymond F. Yates, Reginald P. Lyman, Lewis A. Terven, John C. Strobel, Jr., E. C. Hansen, B. S. McCutchen, John C. Warner, H. M. Lewis, Harry Sadenwater, J. F. J. Maher, George E. Oliver, W. A. Peterson, W. A. MacDonald and R. L. Duncan.

Those approved for direct election to Member grade are: R. S. Glasgow, R. R. Ramsey, C. H. Thompson, W. H. Frasse, E. R. Stoekle, G. C. Furness, C. Wright, Thomas Walmsley, R. T. St. James, R. Highleyman, P. A. Greene, G. J. R. Fisher, H. T. Tisshaw, H. T. Tisshaw, C. E. Scholz, F. W. Dane, F. T. G. Townsend, Harold Roess, P. J. Schwartzhaupt, H. P. Corwith, A. C. Lescarboura and J. Joseph.

Eighteen applications for admission or transfer to Member grade were disapproved.

Messrs. Frederick K. Vreeland and E. T. Fisk were transferred to Fellow grade.

Sections

In accordance with the provisions of the new Section By-Laws, remittances have been made to each Section covering the per-member rebate due for the first quarter of 1926. This financial assistance to the Section already has given new impetus to Section activities.

Headquarters Offices

The new and enlarged offices now occupied by the INSTITUTE at 37 West 39th St., New York, are well organized so that the business of the INSTITUTE may be carried on on a larger scale and all matters attended to promptly. A considerable amount of new furniture and equipment has been added to the plant.

Membership Committee

The membership Committee held a meeting at headquarters on April 5. The following were present: H. F. Dart, chairman,

and Messrs. R. H. Marriott, M. Berger, W. G. H. Finch, A. R. Nilson, E. R. Shute, and President McNicol, ex officio. The committee has worked out a construction program having in view gains in membership, including all those who are eligible and who desire to avail themselves of the advantages of membership in the INSTITUTE.

Seattle Section

The Seattle Section at its March meeting had a paper by Mr. T. M. Libby, on "Some Studies on Radio Broadcast Transmission," and a paper by Mr. John Greig, entitled "High Frequency Beam Transmission." Regular meetings of the Section are held in the rooms of The City Electric and Fixture Company, 218 James St., Seattle. Members of the INSTITUTE who visit Seattle are invited to get into touch with the chairman or the secretary, whose address may be found on a preceding page of this issue of the PROCEEDINGS.

The April meeting of the Section had for consideration a paper by Albert Kalin, on the subject: "Construction and Design of Transformers."

Chicago Section

The Chicago Section held its April meeting in the rooms of the Western Society of Engineers, Chicago, on which occasion Prof. R. R. Ramsey, of Indiana University, presented a paper on "The Resistance of a Radio Condenser at Radio Frequency."

Chicago has the largest of the Section units, and the work is being well handled by Chairman Montford Morrison, Secretary L. R. Schmidt and Treasurer W. W. Harper.

The March meeting of the Section had for consideration a paper by C. M. Jansky, Jr., on the subject: "Collegiate Training for the Radio Engineering Field."

Changes of Address

Members of the INSTITUTE who change their mailing addresses are requested to advise the Secretary of such change. If this is done promptly delay will be avoided in receiving the issues of the PROCEEDINGS and other Institute publications.

Vice-President Bown in England

Dr. Ralph Bown, vice-president of the INSTITUTE, has been in England during the months of April and May, on official business, in connection with Trans-Atlantic radio telephone development.

Standardization Committee

The Standardization Committee held a meeting at INSTITUTE headquarters on March 25, the following being present: L. E. Whittemore, chairman, and R. H. Marriott, C. B. Joliffe, L. A. Hazeltine, R. H. Manson, H. M. Turner, and President McNicol, ex-officio.

Admissions Committee

The Admissions Committee holds monthly meetings for the purpose of passing upon all applications received for direct election to Member grade, and for transfer to Member and Fellow grade. The committee's recommendations in each case go to the Board of Direction, which meets on the first Wednesday of each month.

Meetings and Papers Committee

The Meetings and Papers Committee, under the direction of Mr. R. H. Marriott, chairman, holds regular monthly meetings, in addition to which a continuous correspondence is carried on by the chairman during the month. At the April meeting of the committee the following were present: R. H. Marriott, D. K. Martin, Carl Dreher, W. W. Brown, L. E. Whittemore, R. A. Heising, L. A. Hazeltine, H. F. Dart, and President McNicol, ex-officio.

Photostats of Pages of PROCEEDINGS

Some of the early issues of the INSTITUTE PROCEEDINGS are out of print and are not available. However, photostat copies of pages desired can be supplied to members or others at a cost of twenty-five cents per page. The time required is one week in addition to time of mail travel.

Members Elected

At the May meeting of the Board of Direction the report of the Admissions Committee was approved, covering the transfer to Member grade of: J. K. Henney, J. M. Clayton, Sylvan Harris, H. Stewart Price, J. W. Milnor, C. F. N. Wade, J. G. Swart, J. C. Van Horn, Chester W. Rice, Alfred Crosley, Minton Cronkhite; direct election to Member grade of: H. M. McClelland, H. J. Vannes, W. K. Wing, Meade Brunet, Frank A. Brick Charles Horton, G. C. Southworth, and transfer to Fellow grade of Mr. E. H. Colpitts.

Institute Medal Award for 1926

The INSTITUTE Medal for 1926 has been awarded to Mr. Greenleaf W. Pickard for his contributions as to crystal detectors, coil antennas, wave propagation and atmospheric disturbances. The Medal will be presented to Mr. Pickard at the June meeting of the INSTITUTE in New York.

Washington Section

At the February meeting of the Washington, D. C. Section a talk was given by Major J. O. Mauborgne, of the Signal Corps, on the subject: "The Influence of the 1925 International Telegraph Conference at Paris, on the Coming International Radio Conference at Washington."

At the March meeting a talk was given by Eugene Sibley, of the Air Mail Service. Mr. Sibley described the problems involved in maintaining communication with the Postal airplanes, and in directing their course by radio. The various direction-finding methods tried, culminating in the adoption of the interlocking system—which appears most promising, were described.

At the April meeting Mr. Marcus C. Hopkins presented a paper on: "The Translation of Electro-Mechanical Movements into Sound Vibrations."

The monthly meetings of the Washington Section are held on the second Wednesday at 8 P. M., in the Department of Commerce Building, 19th and Pennsylvania Avenue, N. W.

Additional Sections

Correspondence is now under way looking to the establishment of INSTITUTE Sections at Cleveland, Ohio; Detroit, Michigan, and Winnipeg, Manitoba.

Papers Available in Pamphlet Form

The following papers are available in pamphlet form, copies may be obtained free by members by applying to the Secretary. Price to non-members, 50 cents per copy.

"Radio Station KDKA." By D. G. Little and R. L. Davis.

"Dry Cell Radio Batteries." W. B. Schulte.

"The Present Status of Radio Atmospheric Disturbances." By Louis W. Austin.

"The Shielded Neutrodyne Receiver." J. F. Dreyer and R. H. Manson.

"The Polarization of Radio Waves." By Greenleaf W. Pickard.

"Servicing Radio Broadcast Receivers." By Lee Manley and W. E. Garity.

"New Method Pertaining to the Reduction of Interference in the Reception of Wireless Telegraphy and Telephony." H. De Bellescize.

"Recent Advances in Marine Radio Communication." By T. M. Stevens.

"Main Considerations in Antenna Design." By N. Lindenblad and W. W. Brown.

"Transmission and Reception of Photoradiograms." By R. H. Ranger.

Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies." Axel G. Jensen.

"Maintaining a Constant Reading on an Ammeter in the Filament Battery Circuit of a Thermionic Triode." By E. H. W. Banner.

"Uses and Possibilities of Piezoelectric Oscillators." By August Hund.

"A Radio Field Strength Measuring System for Frequencies Up to Forty Megacycles." By. H. T. Friis and E. Bruce.

"Precautions for the Radio Inventor." By Everett N. Curtis.

"Collegiate Training for the Radio Engineering Field." By C. M. Jansky, Jr.

"Sources of "A," "B," and "C" Power." By W. E. Holland.

Standardization Committee

A meeting of the Standardization Committee was held on March 25, at the offices of the INSTITUTE.

At the invitation of the U. S. National Committee of the International Electrotechnical Commission it was agreed to give that Committee active assistance in its work looking toward the adoption of standard graphical symbols for radio.

After some discussion of the field of work which the Standardization Committee of the INSTITUTE should undertake during the present year, it was agreed that the full activity of the committee should be devoted to the formulation of methods of expressing and measuring, the characteristics of radio receiving apparatus and associated circuit elements and devices.

It was agreed to organize five subcommittees to undertake this work. The subjects assigned to the subcommittees are as follows:

1. VACUUM TUBES—L. A. Hazeltine, Chairman.
   Methods of measuring characteristics.
   Life testing methods.
2. CIRCUIT ELEMENTS—Professor H. M. Turner, Chairman.
   Methods of measuring:
      Resistance.
      Inductance.
      Capacity.
      Power fractor, phase angle or decrement.
      Frequency.
      Coefficient of coupling.
3. RECEIVING SETS—Dr. J. H. Dellinger, Chairman.
   (Including amplifiers and audio transformers).
   Methods of expressing and measuring:
      Selectivity (including effect of shielding).
      Amplification or sensitivity.
      Trueness of reproduction or fidelity.
      Distortion.
4. ELECTRO-ACOUSTIC DEVICES—R. H. Manson, Chairman.
   Methods of expressing and measuring:
      Frequency characteristics.
      Efficiency.
      Distortion.
      Impedance.
5. POWER SUPPLY—R. H. Langley, Chairman.
   Life testing of batteries.
   Method of rating batteries.
      Voltage.
      Internal resistance.
   Socket-power units.
      Voltage-current characteristics.
         Output circuits of different impedances.
         Fluctuating input voltages.

The committee considered several other questions which might fall within its scope, but felt that unless members of the committee who were not present felt otherwise, it would be wiser to concentrate the efforts of the present year on the program outlined above.

It was agreed that the subcommittee chairmen would organize their committees promptly and undertake to prepare a draft of a report within the next two or three months. This is desirable in order that the committee members may have drafts for con-

sideration during the summer months and so that drafts may be available for discussion and criticism at the meetings of the associations of manufacturers.

The committees will include in their reports any new definitions or suggested symbols not included in the 1926 report but which they find desirable in the course of their work.

ADDRESSES AT THE FIRST CONVENTION OF THE INSTITUTE OF RADIO ENGINEERS, NEW YORK, JANUARY 18 AND 19, 1926

OPENING REMARKS OF DR. J. H. DELLINGER, RETIRING PRESIDENT

The constitution of the Institute provides that there shall be held an annual meeting of the Institute. In the sense originally intended by the constitution, such a meeting has never been held. It is true that the Institute has a meeting every month and that the first meeting of the year or any other occasion can be considered as the annual meeting. However, this year the Board of Direction decided to have a specifically set occasion which should be considered as an annual meeting to take stock of the affairs of the Institute and mark its progress. That, in brief, is the origin of this, the first convention of radio engineers. I am glad that the large attendance at this opening meeting ensures that the convention will be successful in its purpose of permitting radio engineers to meet one another and to take stock of the part that radio engineering is playing in the human drama.

This Institute has been peculiarly well timed to play this part. Beginning in 1912 at the very time when radio was beginning to exercise an important part in affairs, it has been privileged to grow along with the rise of radio and to play something of a directing part in that rise. This meeting marks an epoch in the growth of the Institute. The past year has witnessed a number of changes in the character of the Institute's activities and points toward rapid progress in the various phases of its activities. I shall report on this more specifically a little later.

This is the day of the radio engineer. In the past three or four years there has been widespread popular mystification over how radio is done. People have been inclined to classify it along with the acts of the conjurer or in some cases to link it closely with the deeds of the Almighty. The miracles of radio, actually and in the truest sense, are produced not from batteries, coils and electrons, but from the brain of the radio engineer, and when the processes of radio are analyzed they are no more

mysterious than any other familiar process. This is the day of the radio engineer, in still another sense. Progress in radio has been up to the present by empiricism. Its foundations have now been laid. The outlines of its major forms of service to humanity now appear and the task of perfecting this service and its instrumentalities is the task of the radio engineer. He must and he can apply the principles of science and technology to advance beyond the empirical foundations of the subject and obtain from it, by both logical and laborious procedure, all of its possibilities.

There is no need for me to delay the convention getting under way in order to dilate upon or even to mention the achievements or the status of radio. Suffice it to say that those who work in it belong to a recognized branch of engineering which has a unique responsibility. It has been said that the progress of civilization consists in learning how to better employ and transform energy. Such words as these state the mission of all engineers, but the material with which he works takes the radio engineer beyond even this control of physical energy, for the uses of radio today have vitally to do with the use and control also of human energy. A well-known radio engineer in one of his moments of tribulation said that these days a radio engineer must be all of the following things: an electrician, a physicist, an expert in acoustics, a mechanical engineer, a musician, and a diplomat. It is a fact that radio has become a large subject. A few years ago, within our own lifetimes, it was an apt saying that no one person could know all the sciences. The multiplication and ramification of knowledge has now become so great that, as any of us in our more ingenuous moments will admit, no one person can even know all of radio. I suppose that we can say that this branch of engineering has arrived, when it has become so specialized that a person working in one branch of it can give an intelligent disquisition that his fellow members in the profession are not able to understand.

Radio engineers can take great satisfaction not only in the particular field that lies before them but also in the substantial manner in which progress is going forward. We have perhaps gone beyond the point where the daily newspapers turn to radio for the creation of a daily sensation, but to the engineer who really knows what is being done there are many substantial advances and improvements in active progress at the present time. The uniform forward movement along the whole front of radio problems and activities is a genuine cause for optimism,

and optimism is conspicuously the attitude of all workers in radio whether in its engineering, scientific, commercial or social aspects. I would not be misunderstood as intimating that its problems are solved,—by no means. The existence of a number of healthy man-sized problems is what gives zest to the game.

The chief concerns of radio engineering just now are: perfection of broadcasting, and the penetrating of the mysteries of radio wave propagation. These can be considered as, in a sense, a single problem since the first cannot go very far forward without the second; yet these two comprehend broadly the two major streams of engineering thought and effort at present. There has been great progress and fine achievement in both of them during the past year.

These two things have been chosen as the main themes of this convention; the one, broadcasting progress, will be the subject of our thoughts at tonight's meeting which will be a symposium on the results of the radio conference held in Washington in November, 1925. The other problem, the vagaries of radio waves, is the general theme of the two scientific sessions of the conference.

Status Report on Institute Activities

It is my duty to outline briefly the progress of the Institute during the past year. The business matters of the Institute are handled by the Board of Direction, an elected body of twelve members which meets once a month. During this year the custom has been inaugurated of presenting to the membership a regular summary of the business transacted. This has been done through a verbal report by the President at each meeting of the Institute and through the bi-monthly section on "Institute Notes" in the Proceedings. The work of the Institute is done mainly through five standing committees. These committees have been active and not merely decorative.

The outstanding progress of the year has been the growth of the sections of the Institute at various points throughout the country. At the beginning of the year there were four such sections, those of Boston, Washington, Seattle and San Francisco. There was little outward evidence of activity on the part of some of these Sections. During the year Sections have been organized in Chicago, Philadelphia and Toronto. The Toronto Section is the first section to be established outside the United States although the Institute has always had a substantial membership in foreign countries. The desirability and

possibility of organizing overseas Sections is one of the interesting questions which is engaging the thought of the Board of Direction at the present time. In any event there are a number of cities in the United States in which Sections will doubtless be organized in the next year or two. The growth of the Sections is greatly stimulated by the action of the Institute this year in providing a number of special measures, including financial support, for the regulation and encouragement of the local Sections. This progress has been made possible largely through the work of Mr. McNicol, our newly-elected president, who, as chairman of the Sections Committee, made trips to a number of the cities to help organize and stimulate Sections and in other ways has put a large amount of time into this most important part of the Institute's work.

During the year the membership has increased. It should be borne in mind that most persons must join the Institute as Associates. The rather rigid requirements for the grades of Member and Fellow are faithfully observed by the Board, and very careful consideration is given to every application for membership in these grades. This careful work by the Board in the matter of membership which has become a tradition, ensures that election to the Member or Fellow grade is a recognition of professional attainment which is worth something to any radio engineer.

It is a particular pleasure to report that the financial status of the Institute has changed from a deficit at the end of last year to a substantial balance at the end of the year just closed. Effective in 1926, the Institute has found it necessary to raise the dues by a small amount. While such a measure is always unwelcome, it was rendered inevitable by the expansion of activities which the Institute could no longer avoid. Proper stimulation and development of the work of the various local Sections is alone a sufficient cause for this need of increased income. As a partial paliative to the raise in dues, members will receive with the first PROCEEDINGS in 1926 an excellent printed report which gives the result of two years' work by the Committee on Standardization in the way of standard terminology, definitions, and graphical symbols. This will be followed by a Year Book which will include a complete address list, the constitution and section by-laws, and general information about the Institute.

This Standardization Report is a document which is expected to be the basic standard of radio language for the next two years,

which is the approximate period allowed before a new edition of the report may be necessary. Radio has now become stabilized to the point where it seems desirable and worth while for the Institute to undertake standardization work of considerably broader scope. It may therefore be expected that the activities of the Standardization Committee during the coming year will progress to questions of measurements, tests, specifications, etc.

The meetings of the Institute during the past year have been marked by a broadening of the scope of subjects treated. As broadcasting has come to absorb the work of a majority of the radio engineers, a much wider field of topics has become available and necessary for the programs of the Institute meetings. This tendency has been recognized in the papers chosen and presented during the year.

This has been in part reflected in the articles published in the PROCEEDINGS. That periodical has maintained its well-known high standard. The interest of the PROCEEDINGS has been heightened by the addition of the section, "Institute Activities," an innovation which has been very popular with the membership. The volume of material offered for publication has been so great than an undesirable number of months intervenes between the submission of papers and their final appearing in print. The Board has therefore given very careful consideration to the possibility of changing the PROCEEDINGS from a bi-monthly to a monthly periodical. While no definite plans can be made as yet, it may be tentatively forecast that the PROCEEDINGS will be changed to a monthly periodical at the beginning of 1927. It has already been necessary to provide additional editorial service. Arrangements have been made during the year with the Editor of the *Journal* of the American Institute of Electrical Engineers for certain assistance in the editing and publication of our PROCEEDINGS.

There is one point concerning the character of papers presented at the meetings and printed in the PROCEEDINGS on which I think it necessary to give a warning. There is considerable temptation for a radio engineer to use such papers for purposes of commercialization. In yielding to this temptation to secure advertising either in the presenting or in publication of a paper tends directly toward the institution of censorship or, shall we say, toward the requirement of severe editing. Either is undesirable both from the viewpoint of those who present papers or of the editorial staff of the Institute. The proper place for com-

mercial expression in the PROCEEDINGS is in the advertisements. It is worth mentioning, incidentally, that special attention has been given to the advertising this past year and an extremely high grade of appearance and character can be observed in the advertisements published in the PROCEEDINGS.

The year has been marked by a broadening of the affiliations of the Institute. It has become an affiliated society of the American Association for the Advancement of Science and is represented on the Council of that institution. It has become a subscribing member of the National Fire Protection Association and as such will participate in the formulation of national electrical codes. The Institute has also been active in the work of the American Engineering Standards Committee, through participation in some of its committees. These include the Sectional Committees on Radio, on Symbols and Abbreviations, on Batteries, and on Drafting Methods.

Symptomatic of the increasing activities of the Institute, a definite overhauling of the constitution is under consideration. This is being done in no hurried manner. It is thought that a revised constitution will be drafted during the coming year. The committee, of which the present speaker is chairman, has this work in hand and will be glad to receive any suggestions from the membership. The office of the Institute has just taken larger quarters and is a hive of activity. This activity is a reflection of the loyal support, enthusiasm, and interest of the Institute's members all over the world. I know of nothing which so fully illustrates this interest and activity as the present convention with its well-laid plans, fine attendance, and every prospect of success.

NEW OFFICERS

It is now my pleasure to present to you the new officers of the Institute. The gentleman whom you have elected president for the coming year is the man who has been responsible for most of the progress made during the past year. He has done anything but fill the usual role of a vice-president. Instead, he has taken it upon himself to be very active, and such outstanding achievements as the organization of the Chicago and the Toronto Sections are to be credited to his zeal. If the new president receives support this year in proportion as he has given it in the past year, he will have very little trouble in carrying the Institute a long way toward its destiny in 1926. I bespeak such support for him. He is a man of very wide

experience in engineering organizations. He has been active for many years in both the Institute of Electrical Engineers and the Institute of Radio Engineers. He is known as a friend of the young engineer, and perhaps nothing better can be said of a man who has established himself in his profession. He has a most unusually complete and extensive library covering the whole field of the profession. He is a man familiar with the mechanisms of publicity, having had wide experience in editorial work, which is one of the main factors in the growth of an organization such as this. All who love the Institute and have ideas or plans for activities will find fertile soil for their development this year. I am very glad to present Mr. Donald McNicol, the new president.

Address of President McNicol

There may be societies in which the office of President is mainly an honorary elevation, but in the Institute of Radio Engineers the post is a place where the eight-hour-day is in bad standing. The growth of the Institute in the past two or three years has been such that the routine work and the problems of management have enlarged considerably.

It is a credit to past-presidents and to past Boards of Direction that the Institute survived through the hectic years of fundamental invention in radio, and a greater credit still that its prestige and influence have spread widely, always on sound foundations. The most an incoming president may hope for is that he will succeed in maintaining the standards established, while pressing on with a view to further growth and greater usefulness.

The Institute is a clearing house for radio scientific knowledge and literature and its main purpose is to get this information into circulation among the present and oncoming generations of radio engineers.

I am fully appreciative of the honor of serving the Institute as President, following illustrious predecessors such as Dr. Kennelly, Dr. Langmuir, Dr. Pupin, Mr. Marriott, Mr. Pickard, Mr. Hogan, Dr. Alexanderson, Prof. Morecroft, Dr. Pierce, and Dr. Dellinger.

* * * * *

The Institute has elected as its vice president a man who, like the new President, has been active in its service. The vice-president-elect was the chairman of the Standardization

Committee, the excellent fruit of whose labors I have already mentioned. While comparisons are always odious, I believe in rendering tribute where tribute is due, and have no fear of contradiction when I say that the best paper presented to the Institute in 1925 was one by this same gentleman and his associates, a most remarkable contribution to scientific knowledge of radio signal fading. The gentleman whom I am about to introduce has a long record of radio service, having served with distinction in the Army during the war and since then in commercial engineering. Our new Vice-President, Dr. Ralph Bown.

Presentation of Memorial to the Secretary of the Institute

In the preceding I have not spoken of the Institute's activities prior to 1925. The new member of the Institute may think that the Institute always existed or that it has been handed down from the dim past, but things like the Institute don't just happen and don't spring suddenly into full-grown life. There has been a period of fourteen years of steady growth, and this growth is but an integral of the work and faith and service of a number of devoted enthusiasts. The Institute is particularly indebted to the pioneers who founded it and built it up in its early years. Such men as Marriott, Stone, Kennelly, Eastham, Simon, Sarnoff, Hubley and Goldsmith are the personalities who should receive the homage of the Institute today for bringing this organization into being. It is a noteworthy fact that the Institute has been developed entirely on voluntary service. Not only have its officers served without reward of any kind but they have contributed substantially to it in more than one sense. Of no person is this more true than of Dr. Goldsmith, who has been Secretary and Editor for many years. In recognition of his conspicuous service to the Institute, the Board of Direction has deemed it fitting to give a definite expression. It is therefore my pleasure to present to Dr. Alfred N. Goldsmith this engrossed testimonial. (Dr. Goldsmith then received a framed testimonial, signed by all members of the Board, containing the following expression:

The Institute of Radio Engineers

To Dr. Alfred N. Goldsmith

in recognition of his service to science in the upbuilding of

The Institute of Radio Engineers

The members of the Board of Direction, as the representatives of the Institute, are happy to give expression to the high honor and esteem in which they hold Dr. Alfred N. Goldsmith, who has served as Secretary of the Institute for the past eleven years and as Editor of the Proceedings *since the beginning. He has given unstintingly of his time; his substance, his ability and gracious good will to the Institute; has personally built into its structure much of the strength it now has, and has continuously borne the burden of its problems. The Board of Direction therefore takes particular pleasure, at this first Convention of radio engineers, in acknowledging to Dr. Goldsmith their deep appreciation of his far-sighted support and guidance of the Institute, and the service he has rendered through it to the progress of science and engineering.*

Presentation of Liebmann Memorial Prize

There was established seven years ago a fund having an income of $500 a year to be used for an annual prize. This is awarded by the Board each year to the engineer who has made the most valuable recent contribution to the art and science of radio.

I mentioned that one of the two main themes of this Convention is radio wave propagation. It is altogether fitting that one event of our program should be an act of recognition of an outstanding event in this field. Beginning in 1920, working first rather as an amateur than as a member of the Westinghouse staff, Mr. Frank Conrad made the bold departure of establishing regular radio communication on frequencies of 2700 and 5000 kilocycles. He made the startling discovery that there was actually better transmission under some conditions, and less fading than on low frequencies. This and related facts are now very familiar, but at that time it was an overturn of all conceptions of wave phenomena to find that the irregularities of transmission did not increase with the frequency. This achievement has been widely heralded. The statement has even been made that the discovery of the potentialities of high frequencies is the greatest step taken in radio since the original invention of radio itself. It is not my function or purpose to weigh the achievement. It is itself a tribute to the amateur, to the Westinghouse Company, to the spirit of experiment and adventure in the human heart, but beyond all this a tribute to Frank Conrad. The previous recipients of the Liebmann Memorial Prize are:

R. A. Weagant, R. A. Heising, L. F. Fuller, C. S. Franklin, H. H. Beverage and J. R. Carson,

And now it is my privilege and pleasure to hand the prize for 1925, in recognition of his achievement in the development of high frequency signaling, to Mr. Frank Conrad.

MAIN CONSIDERATIONS IN ANTENNA DESIGN*

By

N. Lindenblad

Radio Corporation of America

and

W. W. Brown

General Electric Company

Introduction

The purpose of this paper is to present the outstanding features which need be considered in choosing the rating of a high power transmitter, with particular reference to the design of the antenna. The fundamental data presented herein pertain mostly to trans-oceanic stations which use long wavelengths, and, to a great extent, these data are not applicable to short-wave, long-distance circuits. The better-known features will be referred to briefly, and the features comparatively new will be explained in greater detail.

Conditions of propagation at long wavelengths have proven to be sufficiently dependable for obtaining practical engineering information. The probable reason is the relation between the physical dimensions of the waves and the conditions in space through which the waves are transmitted. Although phenomenal results have recently been obtained over great distances with short waves and low powers, the long waves and high powers are still depended upon for reliable long distance communication.

Preliminary Considerations of a Projected Transmitter

In choosing the wavelength for a long-distance circuit, data available from various long-wave transmitting circuits is being utilized. Mr. Alexanderson and other experienced investigators have found that, for reliable communication, less than five hundred wavelengths should cover the communication distance. This figure is subject to some variation, depending on the direction and location of the communication points, and can be more definitely established after observations during extended periods

*Received by the Editor, February 15, 1926. Presented before the Institute of Radio Engineers, New York, March 3, 1926.

have been carried out at these locations. On account of congestion at certain wavelength bands, it is often necessary to use other than the optimum wavelength.

The rating of a transmitter is conveniently designated as the product of effective height of antenna and antenna current. In order to predetermine the meter-amperes required to provide communication between two points, it is necessary to ascertain the magnitude of atmospheric disturbances at the terminals of the channels. From this information, and having chosen the relation between signal and disturbance intensity required, the meter-amperes of the transmitter can then be calculated. Extensive work in the field has been done by Mr. H. H. Beverage, of the Radio Corporation of America, and others.

The required meter-amperes can be obtained by a combination of large generating equipment and small antenna, or vice versa. There is one optimum value of cost in which a minimum balance is obtained between the cost of all initial maintenance and operating expenditures of the generating equipment against the cost and maintenance of the antenna structure (Figure 1).[1] After these considerations, which really are the most laborious on account of the many estimates that have to be made, the dimensions of the antenna structure can be decided and the design work started—the most economical mast height and mast spacing having already been determined in estimating the optimum cost of each aerial considered in the estimate.

Comparisons of Types of Antennas

In considering the advantages and disadvantages of various types of antennas, both mechanical and electrical features have to be considered. Theoretical evidence and actual performance data obtained from experience determine the type to be selected.

The broadest classification of the various types of antennas may be obtained in classifying them according to their height. Thus, we have antennas of great height and relatively low capacity, and those of lesser height and large capacity. The former type generally employs a centrally arranged system utilizing a few supports of great height, and usually does not lend itself to multiple tuning. One of the main reasons is that the capacity of the superstructure is low and the effective height will be considerably lowered by introducing a number of downleads. Another disadvantage of the high type structure is the relatively high

[1] The Electrical Plant of Transoceanic Radio Telegraphy, by E. F. W. Alexanderson, A. E. Reoch and C. H. Taylor. Journal A. I. E. E., July, 1923.

capacity between the antenna and its supports, which results in lowering the effective height. On the other hand, when antennas of moderate heights are used, these are generally built to cover a large area, and the efficiency of such a system can be made comparatively high by multiple tuning. The lower type antenna, which has a large surface, has a large capacity and its effective height is but little influenced by the introduction of a multiple of downleads. This classification

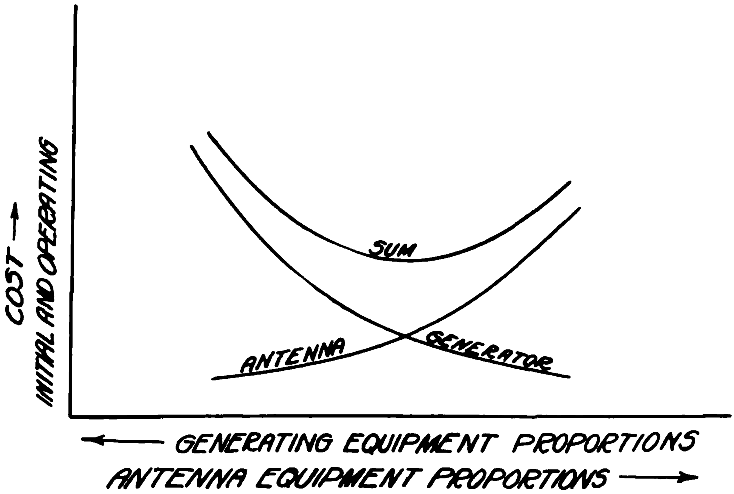


FIGURE 1

applies mostly to large antenna structures. In comparatively small structures, these conditions may be considerably modified.

GROUNDED OR INSULATED SUPPORTS

The question whether supports for large antennas to be operated at long waves should be grounded or insulated from ground is largely an economical one. The insulators are, of necessity, large and expensive and add appreciably to the cost of the supports. Due to the high mechanical loads which the insulators must carry, a number of units are usually used in multiple, and it is very difficult to distribute the load equally among the several units. Replacing damaged insulators adds to the cost of maintenance. The 860-foot support for the umbrella antenna at the Tuckerton Station in New Jersey was originally insulated, but these have been replaced with metal blocks, due to mechanical failures.

A so-called insulated support is, at best, only partially insu-

have bee ... ount of the electrostatic capacity ... owever, the current collected by an tion at ... ly lower than in a grounded support ... capacitive reactance between the other ...

Th ... prod ... nna supports be either well insulated or ord ... conductive base will introduce relatively con ... rs for the antennas at the Radio Central ... are built on concrete bases. Figure 2 ... our bases in multiple for each support is 200

FIGURE 2

... under certain weather conditions. The capacitive reactance ... the antenna to a support is approximately 5,000 ohms. At ... antenna potential of 100,000 volts, the current collected by ... support is 20 amperes. If the concrete bases were not well grounded, the loss would be 80 kw. per support.

For antennas which are to be operated at relatively short wavelengths in which the height of the supports is of the order of a half wavelength or more, the insulation of the supports from ground has certain advantages which do not exist at long waves. At the relatively short wavelengths, grounded supports may cause considerable distortion to the field intensity pattern from the antenna.

CAGES VS. FLAT TOP ANTENNAS

In comparatively small antennas, one or more cages have the mechanical advantage that they are simpler to construct and are less affected by wind than are the flat tops which use spreaders to separate the wires. Electrically, the flat top has a slight advantage in that, for a given average height of conductors, a

slightly higher capacity is obtained. This gives slightly greater effective height and efficiency.

Antenna downleads which are subjected to voltage of 75,000 and above are frequently made in cage form, mainly to avoid corona. The diameter of the downleads should not be made of larger diameter than necessary to avoid corona, as the larger the diameter the greater is the capacity of the lead or leads to ground which lowers the effective height and efficiency of the antenna.

Mechanical Features of Antenna Design

Mechanical Models—Having decided upon the type of structure and its general dimensions, a mechanical model is often useful to aid in forming a conception of the various mechanical features and is particularly useful to check calculated forces in complicated structures. These models are usually made to a convenient scale, and particular attention is given to making the essential parts to have the correct relative weights. With the model in the normal position, the dead weight stresses are measured by a small dynamometer. By tilting the model, gravity then replaces wind conditions. Light chains or soft lead wire have been found useful in such models.

Antenna Supports (Masts, Towers, etc.)—The supports are of two main types: self-supporting and guyed structures. In America, at least, the trend in recent years has been towards the self-supporting type. The self-supporting type, although often of a higher initial cost than the guyed type, offers several advantages. It is less costly to maintain, has less influence on the antenna capacity and, thus, its effective height, and in certain cases, especially at the shorter waves, it causes less complications in tuning phenomenon and absorption. Self-supporting structures can be conveniently constructed with cross arms. These make it possible to arrange the superstructure with considerable width without using pairs of supports, thereby providing a relatively large capacity at an effective height which approaches the physical height.

Wire Material—In selecting wire material for an antenna, the material affording the best compromise electrically and mechanically is chosen. The materials most favorable so far have been found to be silicon bronze and Copperweld steel wires. As more data become available about the latter, it seems to be the better of the two.

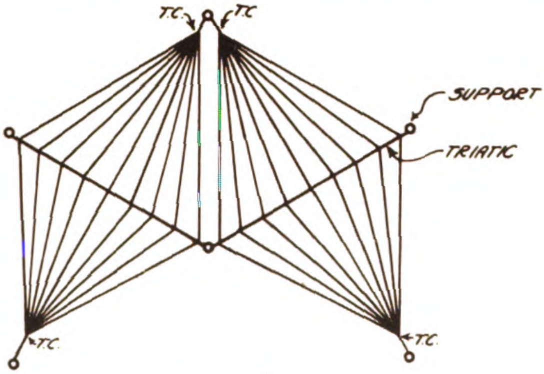
One determining factor in choosing the wire material is fatigue and crystallization of the material. It can be said that

a large aerial employing long spans is never at rest, and these motions in the system cause fatigue of the material. The natural periods of these motions cover a very wide range from high notes of audio frequency down to oscillations that may take several seconds to complete the cycle. It is thought that of these the ones causing the crystallization are those of the higher order. It was found that solid wires were much more subject to crystallization than stranded wires, and this is, of course, only natural, as the stranded wires afford some damping effects due to their construction. But even stranded wires show the same effects, and it cannot be said that this investigation is finished yet. The slower motions have a great wearing effect upon connections and jumpers, as these are continuously subject to back and forth bendings. Although these are mostly of a minute magnitude, it is surprising how enormous the wear can be during a year of service.

Protection from Excessive Mechanical Loads—In order to protect an antenna structure from damage by the weather elements, arrangements must be made to prevent loads in excess of the elastic limit of any portion of the structure. Often this has been done simply by providing sufficient wire sag. This is detrimental to the electric constancy of an antenna during wind, and various means of permitting small wire sags have been introduced. The nature of such arrangements differs greatly with the various antenna types. For antennas of the "Radio Central" type, it is feasible to use very strong wires having a small sag, as the strain in the wire is at no point taken by the masts, which latter merely support the weight of the wire as in a transmission line. The supports for the Radio Central antennas are of the self-supporting type with cross arms. There is one weak point in this type of support which must be safeguarded. In case one or several wires should break, the cross arms would be exposed to an unbalanced load from the remaining spans of this wire and the supports are subject to dangerous twisting. It was, therefore, found necessary to permit the whole wire to drop in case one should break, in order to avoid such a condition. This is accomplished by means of gripping devices at the supports of the wire that will open when the wire load is unbalanced. In order to safeguard against excessive loads should the stresses be great even under balanced conditions, as, for instance, in case of failure of the sleet-melting equipment during a heavy sleet storm, each wire has at one end been equipped with a tripping device which, by releasing the wire at one end of the

antenna, will start an unbalance in the wire stress and cause the wires to drop. By adjusting these tripping devices for different loads, it is possible to let the wires causing the most dangerous loads to drop first. This system has been described in detail by Mr. J. H. Shannon in a paper, "Sleet Removal From Antennas," presented before the INSTITUTE OF RADIO ENGINEERS, New York, September 2, 1925. Provisions to melt sleet from antennas is justified by two reasons: (1) It is a form of insurance against long delays which would be occasioned by damage to an antenna by excessive sleet loads. (2) It reduces the initial cost of an antenna by permitting the adoption of a structure of moderate strength.

Wherever feasible, the use of counterweights is a very satisfactory method of safeguarding against excessive stresses in an antenna. For the Radio Central type, this is impracticable, and, therefore, other designs have been tried in which it was attempted to combine the advantages of a long flat top antenna and to employ counterweights. This antenna is designated as the diamond type. One of the antennas at the Tuckerton Station is of this type. Figure 3 shows a plan view. This antenna is multiple



PLAN VIEW
"DIAMOND" ANTENNA AT TUCKERTON STATION
TUNED AND COUNTERWEIGHTED AT POINTS "TC"

FIGURE 3

tuned at the points designated in the figure and the spans are counterweighted at the same points. Figure 4 shows the arrangement of the downlead at the outside end of a diamond in Figure 3 and Figure 5 shows the arrangement of the two downleads at the inside ends of the diamonds in Figure 3. The antenna de-

signed for the Pernambuco Station is of the diamond type and is shown in Figure 6. The diamond type requires one extra mast for every two spans, but this is partly compensated for by the greater width that can be used and thus is not so uneconomical. The great advantage of this type is in its mechanical features,

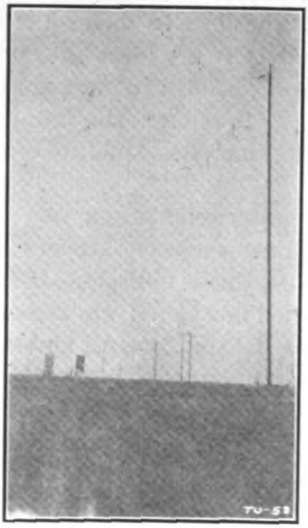
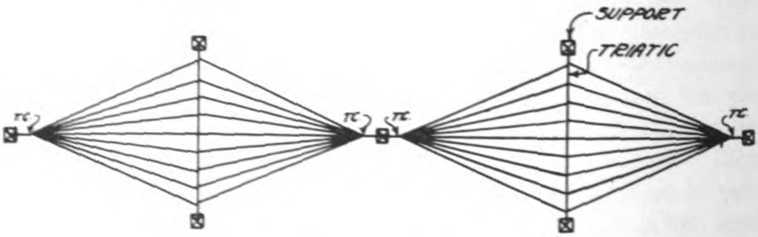


FIGURE 4

FIGURE 5



PLAN VIEW
"DIAMOND" ANTENNA FOR PERNAMBUCO STATION
TUNED AND COUNTERWEIGHTED AT POINTS "TC"

FIGURE 6

in that it can be counterweighted at one end of every span and the counterweight be given such a weight that the elastic limit of the wires can never be reached. The performance of this antenna type has been studied and found to work as expected. During a sleet storm at Tuckerton, the power supply failed and

thus prevented the melting of sleet. The counterweights merely permitted the antenna to assume an enormous sag. Of course, the antenna could not have been used while in this position, even if power had been available. As soon as the power supply was available, the sleet was melted, the antenna resumed its normal position and traffic was resumed without extra delay due to repair work. Counterweights are always used in anchoring downleads, regardless of antenna type.

Electrical Features of Antenna Design

Capacity Calculations and Measurements of Models—In the calculation of antenna capacities, the problems are often so complicated that it is not practicable to attempt a theoretically exact solution, which is possible only for very simple types of antennas. An outline will be given of the methods which have been found most useful and which are sufficiently accurate for practical purposes. The basic principle of the most useful method is to convert the physical arrangement of conductors to such forms that the well-established formulas for the capacity between concentric cylinders and between a cylinder and plate can be used.

Of the several components which constitute the total antenna capacity, the largest component is usually that of the horizontal or top section to ground. This component is again subdivided into wire to plate capacity and plate to ground capacity; these two components are in series. Consider the horizontal section as being composed of a number of wires equally spaced apart and parallel with the ground. The wire-to-plate capacity is determined by considering each wire as being surrounded by a cylinder whose circumference is equal to twice the spacing between the wires. The capacity of each wire to its concentric cylinder times the number of wires gives the wire-to-plate capacity per unit length of the wires. The plate-to-ground capacity is determined by considering the wires to be replaced by a cylinder whose circumference is equal to twice the spacing between adjacent wires times the number of wires. The capacity of this cylinder to ground is equal to the capacity to a concentric cylinder whose diameter is four times the distance from the antenna wires to ground.

In the case of a long flat top antenna of constant width, the conversion to concentric form is simple. In the case of a diamond antenna, the conversion is less direct and the results less accurate, especially when the width exceeds twice the height.

In all cases in which a large number of wires is considered,

regardless of the geometrical form, it is well to obtain the plate capacity, which is the capacity of a metal sheet of the same outline as the antenna. If the antenna is low compared to its length and width, the plate capacity and a small factor for edge effect gives the true capacity. As the height increases, the factor for the edge effect increases and this factor can not be estimated unless special data are available.

In order to check calculated capacities, especially in geometrically odd design, it is well to measure models. If models for measuring capacity directly were to be built, these would have to be rather large, and would involve a considerable expenditure of time and money. A method much better and very reliable is the water-box method, which utilizes measurement of resistance rather than of capacity. There is required a water-tight wooden tank with a metal plate covering the bottom, or a metal tank with the inside side-walls dressed with some insulating material and the bottom of this tank uncovered. A standard consisting of a circular disk and surrounded by a concentrically arranged shield ring (Klevin ring) is used. Both the disk and ring are fastened to a plate of some insulating material so that only one side of them is uncovered. If the disk and its associated ring are mounted above and parallel to the bottom of the tank with the metal side facing the bottom, the capacity of the disk can be very closely calculated as it is a straight plate condenser without edge effect, due to the shield ring which always is given the same potential as the disk. The edge effect will thus only appear at the outside edge of the shield ring and not come into consideration. A model of the antenna plate is now made to some convenient scale, comparing in size with the standard. Insulated leads are attached to the model and the disk and ring of the standard. The apparatus is now placed in the tank, which is filled with water. The capacity of the standard is known. The resistance of the standard as well as that of the model can be measured, and thus the only remaining unknown factor is the capacity, which can be calculated from these values, as the current lines radiating from the model have the same physical shape as the electrostatic lines. Thus, the lower the resistance of the model, the higher is its corresponding capacity. This method is very reliable and has been found useful for checking purposes in complicated cases.

In case a model employing wires is used, it is impossible to use wires small enough to correspond to the scale. The smallest practicable wire is used in the model, and, when enlarged to

full scale, is considered the outside cylinder around the actual wire.

In order to get an idea of the correct number of wires to be used, it is often advisable to calculate the so-called wire factor which is the ratio of the total capacity of the flat top to its plate capacity. If the supports are strong enough, this factor should be made high. On the other hand, when a support of given strength is available, the factor should be made low, as this means that the wires have been spread apart as much as possible and thus the greatest possible capacity has been obtained with a minimum of wires.

Resistance—Representative

A segregated list of the various components of resistance of one antenna at Radio Central Station is as follows.[1]

Radiation resistance at 16,500 meters	0.05 ohm
Soil resistance	0.10 ohm
Tuning coil resistance	0.15 ohm
Conductor resistance	0.05 ohm
Insulation and other losses	0.05 ohm
Total	0.40 ohm

With a given arrangement and dimensions of an antenna, the radiation resistance at a given wavelength is definitely established. The other factors which represent losses are subject to considerable variation, largely under control of the designers.

Radiation Resistance

This element can be calculated by well-established formulas.[2] These formulas contain a factor for the effective height which can also be calculated, but not to the same accuracy as in some simpler problems. After a station has been erected, a check on the calculations of effective height can be obtained by measuring the field intensity at a given distance from the transmitter and by calculating the effective height of the transmitting antenna from these data. Close agreement has been obtained between the two methods of determining the effective height.

Soil Resistance

This item is usually a larger part of the total resistance than is shown in the segregation which applies to a "Radio Central"

[2] Transoceanic Radio Communication, by E. F. W. Alexanderson. G. E. Review, October, 1920.

antenna. A careful study of the various factors involved in the arrangement of a ground system and the application of well-established principles is well worth while.

The fundamental principle of keeping the soil resistance low is to provide short paths for the current through the soil. If the resistance of the soil is low, pipes or buried plates may be used to good advantage. If the resistance is high, which is the usual condition, buried wires are preferable. The unit resistance of dry sand is more than 500 times the resistance of salt marsh. Actual measurement of soil resistance is very necessary before a ground system can be properly designed.

The ground currents should be collected according to the area of ground around the point of collection and according to the field intensity at this point. It has been found necessary to arrange the buried wire system so that it can be tapped at a great number of points and the current carried back to the tuning coil center by means of an overhead conductor. To effect an orderly arrangement, the tapping points are generally arranged in symmetrical rows and these rows are connected to a main overhead bus which connects to the antenna tuning coil. As the currents are collected along this bus, the current passing through the bus and the inductive voltage drop along the bus become greater as the tuning coil is approached. If, therefore, it is desired to collect equal currents at each grounding point, it is necessary to insert an inductive reactance at this point which has a value corresponding to the voltage of the overhead bus divided by the current to be collected. This is equally true in connecting up the antenna supporting structures and other structures with the ground return system. The currents collected by these structures are first ascertained, and then the proper reactance in the connecting link is calculated from the voltage of the collecting bus and the current to be collected in order to maintain the natural current distribution, which depends upon the distribution of the electric field from the antenna.

It can readily be seen, however, that in an antenna of great proportions and with the heavy currents that would have to be carried along the busses, or in case of a counterpoise, considerable inductive voltage drop would occur along the conductor. Thus considerable flux would radiate from these busses and cause circulating currents in the ground. Sometimes, when the bus is not too long, the voltage can be neutralized by series condensers inserted in the line. For extended systems, this is an undesirable complication and has the disadvantage of

correct neutralization at only one frequency. Regardless of the neutralization of the voltage on such busses, the magnetic field from the current they carry still remains and is a source of considerable loss due to induced circulating currents in the ground

The greatest advancement in the solution of these problems was the development, by Mr. Alexanderson, of multiple tuning.[3] The main object of multiple tuning is to provide shorter paths for the ground currents. This is accomplished by distributing the total antenna current through a number of tuning coils spaced along the length of an antenna, rather than to have the total current flow through one coil. The multiple arrangement makes it possible to obtain a ground-distributing system of reasonable proportions and the soil resistance is thereby greatly reduced.

Excellent results have been accomplished by Mr. Hansell and Mr. Carter, of the Radio Corporation, in investigating the phenomena of conduction of current through soils of different characters. These investigators demonstrated mathematically and by experiment that, for a soil of given character, there is a fairly definite length of wire which gives highest conductivity at a given wavelength. This length is approximately one-quarter of the wavelength at the rate of propagation in the particular soil. The rate of propagation in soil is much slower than in air, in certain soils being 1/20 or less of the rate in air. If the length of wire is extended indefinitely, the conductance will pass through a number of cycles of decreasing amplitude, becoming constant at a value which would obtain with an infinitely long wire.

Another method of reducing soil resistance is by the use of a counterpoise—earth screen—and in some cases a combination of wire ground and counterpoise is justified. On account of the importance of reducing soil loss to a minimum, the outstanding factors will be considered.

First, consider an antenna without a counterpoise, having only a buried wire ground. Figure 7 shows the flux distribution of a long flat top antenna. The electric lines of force from the antenna spread a maximum amount and the radiation resistance of the antenna is a maximum. On the other hand, all of the antenna current returns through the soil and through the contact resistance between the buried wires and the soil. On account of the large spreading of the lines of force, a portion of the current travels long distances through the soil. Therefore, if the resistance of the soil and the contact resistance are high, the radiation

[3] Transatlantic Radio Communication, by E. F. W. Alexanderson. PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, August, 1920.

efficiency might be low. If a large area under and around the antenna can be covered with buried wires, the soil resistance can be reduced and the radiation efficiency increased.

Second, consider an antenna with a counterpoise only. There is no contact resistance between the soil and buried conductors. The electric lines of force are pulled in toward the counterpoise. The amount of lines which go from the antenna directly to the

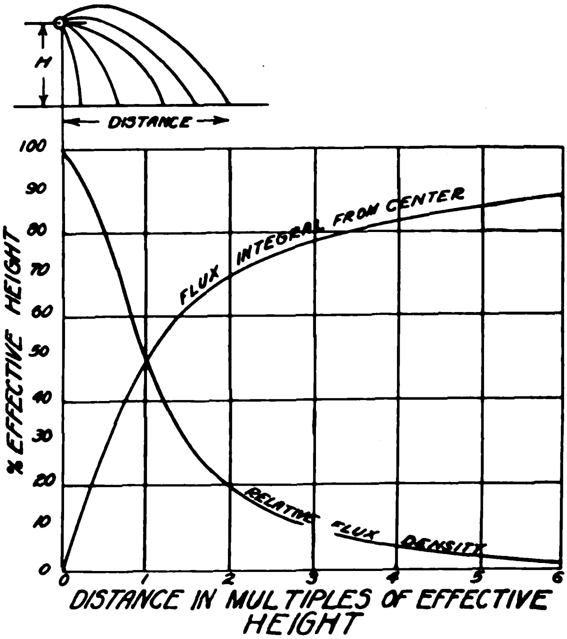


FIGURE 7—Flux Distribution of a Long Flat-Top Antenna

counterpoise is proportional to the ratio of the direct capacity between the antenna and counterpoise and the indirect capacity from the antenna through the ground to the counterpoise. The potentials on the antenna and counterpoise are in inverse proportion to their capacities to ground. The potential of the counterpoise when no ground connection is used is always of opposite polarity to the antenna potential because when the lines go in the direction antenna to ground, they go, at the same time, in the direction ground to counterpoise. Considering the ground to have zero potential, one must be negative when the other is positive. Therefore, the counterpoise radiation is counter to the antenna radiation.

With a counterpoise, the radiation resistance of the antenna is decreased on account of the lines being pulled in toward the

counterpoise and on account of the counter radiation. On the other hand, there is no contact resistance and the currents through the soil are smaller. Therefore, for a given area of counterpoise, there is a certain height of counterpoise which gives maximum radiation efficiency. If the ground area for counterpoise is unrestricted, maximum efficiency of the counterpoise is obtained when it extends over a large area. In this case, the height of the counterpoise above ground should be equal to the spacing beteeen the wires, to prevent any of the lines from the antenna from passing through the counterpoise. Of course, there should be a sufficient number of wires so that the counterpoise can be kept low, thereby keeping the counter radiation low.

Following the preceding line of reasoning, we can readily see the conditions which may justify a combination of wire ground and counterpoise. This condition is obtained when the ground area under and around the antenna is restricted and the soil resistance is high. If a sufficient amount of buried wires is used in this restricted area, the soil and contact resistance for currents within the area can be brought to a very low value. If the ground were stony, it might not be possible to install a sufficient amount of buried wires. Regardless of the amount of wires in the restricted area, the ground currents produced by the lines which would fall outside of the area would flow through high resistance soil. Obviously, it would be advantageous to reduce the currents beyond the restricted area, and we have seen that the counterpoise does just this.

Let us now assume that a first-class buried wire system has been installed in the restricted area, and the soil and contact resistance within this area is negligible. Neglecting the coil, conductor and other relatively small resistances, the antenna resistance is determined by the effective height of the antenna and the resistance of the soil outside the restricted area. By knowing the soil resistance, the effective height can be made such that the radiated energy is as large as possible, compared with the energy lost in the soil outside the restricted area.

The same results can be obtained by using only a counterpoise and no buried ground, provided the counterpoise has enough wires (high capacity) and covers the same area as the buried wire ground system.

Either the buried wire system or a counterpoise structure for a large antenna is very costly. The combination of the two sometimes proves to be the most economical, because fewer wires can be used in both, thus reducing the initial and maintenance costs.

it is feasible to use fewer wires in each because the duties of the two are reduced; the total antenna current is divided between the two. If the counterpoise carried the total antenna current, its potential would be high because its area is restricted, the number of wires and the capacity are small. The higher the potential of the counterpoise, the greater would be the proportion of lines from the antenna to the counterpoise as compared with the lines to the soil beyond the counterpoise. This would result in a lower effective height, because the effective height is determined by the flux distribution.

What is the best distribution of current between the buried wire system and the counterpoise? Consider first the circuit of antenna, inductance coil and counterpoise. With the circuit energized, there is a point on the inductance which has ground potential because the counterpoise potential is counter to the antenna potential. If the buried wire system is connected to this point of ground potential, no change in circuit condition will result. If the ground system is tapped down the coil towards the counterpoise, the total antenna current will be distributed between the counterpoise and wire ground.

As the proportion of total antenna current to current in the buried system is increased, the effective height and radiation resistance increases. The soil resistance also increases and the conditions may be expressed mathematically from the fundamental formula:

$$\text{Radiation efficiency} = \eta = \frac{R_R}{R_o + R_R}$$

as

$$\eta = \frac{R_R + \Delta R_R}{(R_o + \Delta R_o) + (R_R + \Delta R_R)}$$

where ΔR is the increase in radiation resistance, and
ΔR_o is the increase in ground resistance.

For a certain adjustment, the above equation will give a maximum value for η, which is the maximum radiation efficiency.

The combination of buried wire and counterpoise systems has proven useful in decreasing the soil resistance at stations which were built at a time the knowledge on this subject was limited. In these cases, the height of the antenna was fixed and the combination provided a means of adjusting the antenna for a relatively high radiation efficiency. In such cases, a check on the calculated optimum proportion of current in the two systems could be obtained by measuring the field intensity for the antenna with different distributions of current, using the same power

input to the antenna in each case. The maximum radiation efficiency is not necessarily obtained with minimum antenna resistance.

The tendency of the Radio Corporation engineers has been to adopt the buried wire system in preference to the counterpoise or the combination of the two. The main reason is that the buried system is not subject to mechanical or electrical failures, and, therefore cannot cause interruption of service. Thus, the economical factor enters again and in a broader aspect.

Tuning Coil Resistance

This is the largest item of loss given in the segregation for a representative antenna, and therefore justifies careful consideration in connection with long-wave high-power antennas.[4] In the design of such coils, the two most important factors are reliability and efficiency. As a result of investigations over a period of ten years, improvements have gradually been brought about in the early designs, so that at this time there are two types of coils which embody the factors of reliability and efficiency to a high degree. The two types differ mainly in that one is intended for operation outdoors; the other type is for indoor use.

From a reliability standpoint, of first importance, is a large factor of insulation strength. This is obtained by using porcelain for the supports of the conductor and so arranged that long leakage paths over the surface of the porcelain are provided. From an efficiency standpoint, the kind of conductor, proportions of the coil, absence of metal fittings in the supports and low dielectric loss in the supports are important factors.

Figure 8 shows an assembled coil which operates reliably—outdoors—at 18,000 kilovolt-amperes at higher efficiency than a combination of four coils of an earlier type with the same total kv-a. distributed equally. Figures 9 and 10 show, respectively, a spacing block for the conductor and a detail of the porcelain supports which contain a negligible amount of metal.

Figures 11 and 12 show component parts of the unit type coil, and Figure 13 the assembly of a complete unit. These units are stacked, vertically, to the required numbers. This type is intended for indoor use. There are no metal fittings in the supports, and the conductor is of finely stranded Litz proportioned to reduce eddy current losses to a minimum. Coils of this type

[4] Designs and Efficiencies of Large Air Core Inductances, by W. W. Brown and J. E. Love. Proceedings of The Institute of Radio Engineers, December, 1925.

are operating very satisfactorily at 16,000 kv-a. as antenna tuning coils and at 28,000 kv-a. as antenna uncoupling coils. As uncoupling coils, the potential of one antenna is impressed on the bottom of the winding which requires high insulation strength to

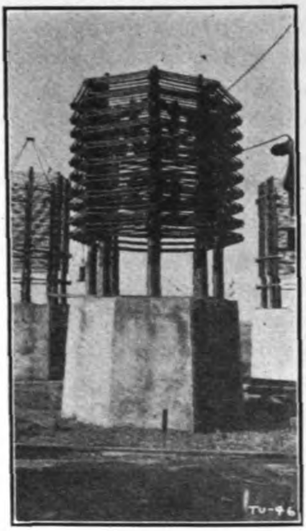


FIGURE 8

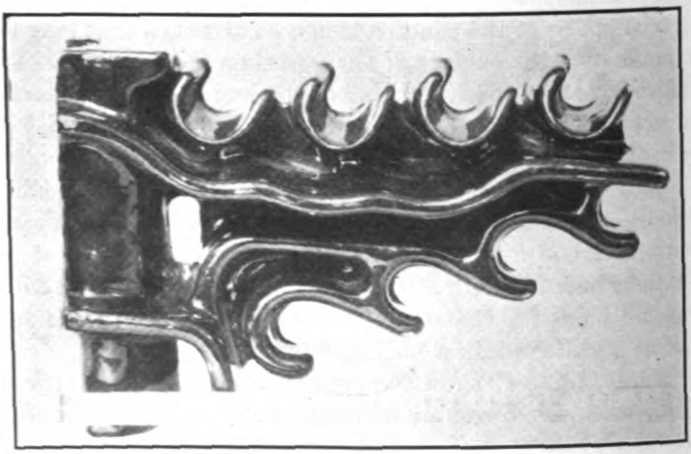


FIGURE 9—Porcelain Spacing Block for the Conductor of Antenna Tuning Coil

ground. This is obtained by using the required number of blank rings between the bottom active section and the concrete foundation.

Each of these types can be proportioned for satisfactory operation at practically any load encountered in connection with high-power long-wave antennas. They are particularly suitable for use with multiple tuned antennas.

Outdoor coils are satisfactory under nearly all climatic con-

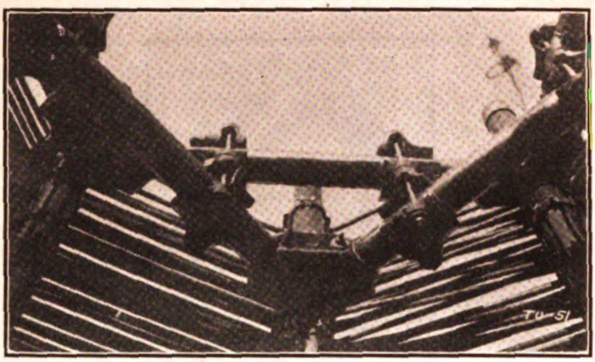


FIGURE 10

ditions, except when so located that salt spray deposits a coating of salt on the coils. This condition necessitates housing around the coils, and other conditions sometimes justify housing. Figure

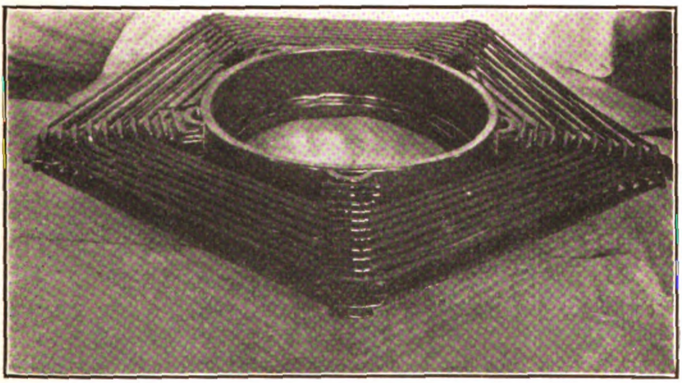


FIGURE 11—One Section of Unit Type High-Power Antenna Tuning Coil

14 shows a house at the Marion Station in Massachusetts of a size suitable to protect one antenna tuning coil and one uncoupling coil. This house is of frame construction, lined with sheet copper; joints between sheets are soldered, and the roof is also of sheet copper. The effect on the electrical characteristics of a coil

by erecting a house around it is to slightly lower the inductance of the coil. The resistance is not appreciably increased.

Conductor Resistance

This element is usually relatively small because of the large number of conductors in the multiple and each conductor is of

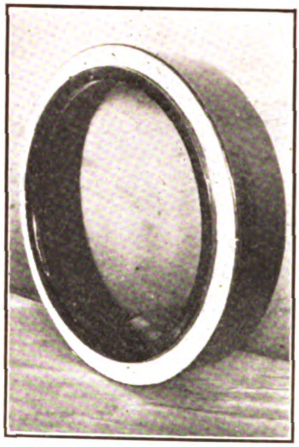


Figure 12—Porcelain Cylinder for Unit Type Tuning Coil, 36 in. Diameter

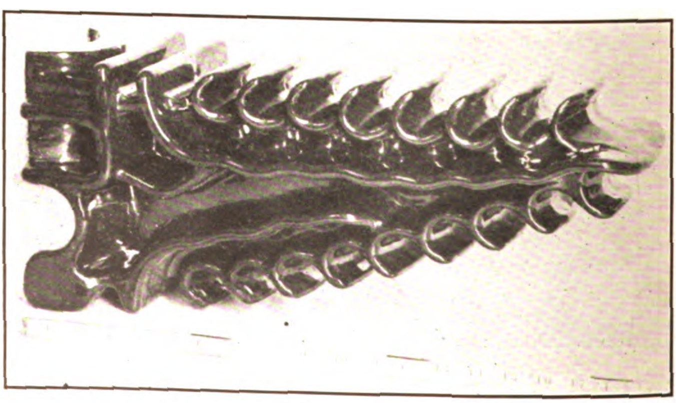


Figure 13—Porcelain Spacing Block with 17 Grooves for High-Power Antenna Tuning Coil

large diameter to avoid corona. For the antenna proper, silicon bronze and copperweld are used almost exclusively. These materials have slightly different resistance at radio frequencies, but the

choice between them is usually for mechanical rather than electrical reasons.

Insulator Resistance

The type of insulator most satisfactory for insulating high-voltage antennas is in the form of a long cylindrical rod or tube with suitable fittings and shields. Porcelain is the material used almost exclusively, and the designs now in use are the result of development over a period of several years.[5] The dielectric loss in one insulator of this type at 100,000 volts is so small that we were unable to measure it accurately. However, in a large antenna there are frequently 100 or more insulators, so that the total

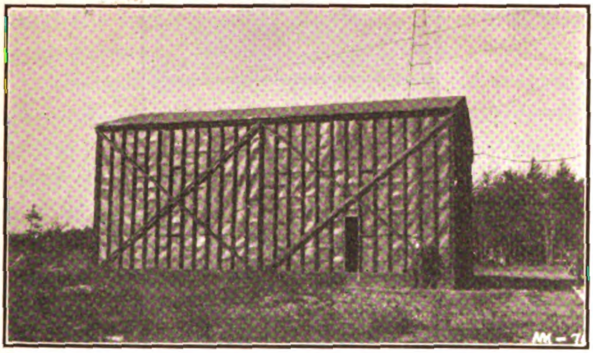


Figure 14

loss becomes appreciable. Correct shielding is very important to obtain satisfactory operation during varying weather conditions.

Indoor tuning coils require lead-in insulators. Several forms of these insulators have been used more or less successfully. The type now gaining favor is shown in Figure 15. A large number of insulators of this type of different sizes, having flahsover values from 30 to 100 kv., is in satisfactory use, and a size having a flash-over of above 200 kv. is being tested. Larger sizes can be made if required. The mechanical strength of these insulators is in most installations sufficient to withstand the mechanical load of the downlead without additional insulators, which were required before this type became available. Electrically, they have proven satisfactory through the range of long waves to as short as 100 meters.

[5] Radio Frequency Tests on Antenna Insulators, by W. W. Brown. Proceedings of The Institute of Radio Engineers, October, 1923.

Corona in any appreciable amount must be avoided in order to obtain otherwise possible efficiency. An antenna curve of Resistance vs. Current shows constant resistance through the range of low and increasing current until the corona point is reached at which the resistance increases rapidly. The corona point in a representative high-power antenna is around 175,000 volts, but in many existing antennas is much lower than this

FIGURE 15—Radio Antenna Lead-in Insulator — Nominal Rating 80,000 Volts

value. This, of course, can be raised by providing larger conductors, greater spacing, etc.

EFFECTIVE HEIGHT

As an antenna always consists of members of different heights and as parts of its wire system often are close to the supporting and other structures, it is necessary to take all these factors into consideration in order to estimate their combined influence upon the effective height of a system.

The factor determining the magnitude of the influence of each member is its capacity, and, as the purpose of the investigation is to find the effective height, the effective height of each part of the system should be taken into consideration. The problem is similar to that of finding the center of gravity of a body.

The products of the capacity and effective height of each portion of the system are added up and this sum is then equal to the sum of all capacities multiplied by the combined effective height which is the unknown factor. This problem is relatively simple when the physical dimensions of an antenna are small

compared with the wavelength that is used, as the effect of uneven voltage distribution can be neglected. When an antenna is large compared with the wavelength used, a third determining factor is introduced, that of the voltage of each portion considered. This sometimes leads to quite involved complications, depending on the design of the structure.

Antenna Uncoupling

When two or more antennas are located close together, difficulties are encountered in simultaneous operation of these antennas, particularly if the wavelengths are close together. These difficulties are due to the capacitive couplings between the antennas, and the methods of overcoming these difficulties are referred to as antenna "uncoupling" methods.

Due to one antenna being present in the electromagnetic field of another antenna, energy is in this way transferred from the latter to the former, and the amount of energy transferred depends upon the voltage of the exciting antenna, the combined impedance of the capacity path between the two, and the impedance of the pick-up antenna. It is evident that several conditions can be obtained, depending upon the impedance combinations between the antennas. The energy collected by an adjacent antenna may be helpful or detrimental to a signal, depending upon whether the energy in the pick-up antenna is in phase or out of phase with the energy in the primary antenna.

The conditions may be divided into two main cases:

1. The secondary antenna is tuned to a lower frequency. The impedance across the second antenna is thus capacitive for higher frequencies. As the coupling reactance is capacitive, there is a successive voltage drop first from the primary antenna to the secondary and then across the secondary. The secondary antenna will thus be in phase with the primary.

2. The secondary antenna is tuned to a higher frequency. the impedance across the secondary is thus inductive. As the coupling capacity furnishes a capactive reactance, a successive voltage drop will no longer take place across the combination as in Case 1. Furthermore, there will occur three different conditions in this case:

(a) The reactance of the coupling capacity is smaller than the impedance of the secondary antenna. Then a portion of the inductive impedance will tune the coupling capacitance. However, as the voltage drop along this

inductive impedance must be continuous and greater than the voltage drop across the coupling capacity, and as the difference between the two is equal to the primary antenna voltage, then this voltage must be in phase with the primary antenna voltage.

(b) The reactance of the coupling capacity is equal to the impedance of the secondary antenna. Then all energy will be transferred from the primary antenna to the secondary as a tuned short circuit has been formed across the primary antenna by the combination of coupling capacity and secondary antenna.

(c) The reactance of the coupling capacity is larger than the impedance of the secondary antenna. As the voltage drop must be continuous along the coupling reactance and greater than that across the secondary antenna, and, as the difference between the two equals the primary antenna voltage, it follows that the primary and secondary antenna voltage are 180 degrees out of phase.

Condition (1) has no detrimental effect from an energy standpoint.

Condition (2) is undesirable as it may happen that (a) the secondary antenna may constitute too great a branch of the tuned circuit of the primary antenna; (b) the energy dissipation is almost entirely transferred to the secondary antenna; (c) the radiation of the primary antenna is considerably neutralized by out-of-phase currents in the secondary antenna.

Thus it can be seen that while Condition (1) in most cases would be desirable as it corresponds to a greater combined antenna system of consequently lowered resistance, this condition is always accompanied by Condition (2), and thus it is necessary to employ means of neutralizing the effect of the coupling between the antennas.

In long wave transmitters, the methods of controlling the antenna energy for signaling depend at least partially on the principles of detuning. Through this action, the keying of one antenna influences the keying of the other in a detrimental manner.

As the coupling is capacitive, it would be most logical to balance this by another capacitance, but unfortunately, the physical conditions of the circuit prevent this procedure. The capacity of the coupling has, instead, usually been neutralized by paralleling the capacity with an inductance, thus forming a parallel-tuned circuit of high impedance between the two antennas. Another method of uncoupling is to introduce an oppos-

ing voltage in one antenna from the other by means of neutralizing transformers. Should it be desirable to completely neutralize for both frequencies, the two methods may be combined. It has been found sufficient to use one of the two methods, and, in America, the shunt tuning of the coupling capacity has generally been used.[6]

Best results have been obtained by having this circuit tuned to a frequency midway between the two antenna frequencies. In this case, the impedance of the uncoupling circuit and the secondary antenna will always be either both capacitive or both inductive and thus insure against opposing phase relations between the primary and secondary antennas. Also, the effect between the two has been greatly reduced, due to the increase in impedance across the uncoupling branch.

Transmission Lines

It is often desirable to locate the antenna at some distance from the transmitter. This is especially true in the case of multiplex stations. Transmission lines will then be required to connect up the antenna with the transmitter. If the physical length of the line is small compared to the wavelength, almost any kind of connecting link forming part of the antenna circuit may be used. The line may either be arranged to feed the antenna in shunt or series. When the physical length of a line becomes great compared with the wavelength used, more specific methods have to be resorted to in order to transfer the energy efficiently and without undesirable tuning phenomena. When a line of these proportions is energized and tuned for the transfer of energy, there is one optimum adjustment at which the transfer takes place with a minimum loss of energy. This adjustment may be called the unity power factor adjustment of the line. At this adjustment—provided we have a perfect line—the current is the same throughout the line, showing the non-existence of standing waves. As is well known, a standing wave of any kind is caused by two waves traveling in opposite directions. In the transient state of charging a line, there are only traveling waves, but, when these reach the end of the line, if they are not perfectly absorbed by correct loading resistance, the remaining energy is stored up magnetically or electrically, as the load resistance is too small or too large to absorb the energy in a given time. This stored energy is then reflected back, due to the electromagnetic pressure caused

[6] Multiple Antenna Installation, by Dr. A. Meissner. Telefunken Zeitung, January, 1923.

...rgy into the elastic medium surrounding the
... ...ing the energy back again over the wire, an
...essary loss takes place. Standing waves occur
... steady state has been reached, the line assumes a
...ance at its ends which depends on its length in rela-
...e wavelength, and often these impedances are of incon-
... magnitudes to fit in with the rest of the circuit. Standing
... can never occur on an infinitely long line as the energy
... never reach its end to be reflected. When the load end of a
...ne of finite dimensions is adjusted so that all incoming energy
is absorbed and none reflected, this corresponds to making the line infinitely long.

In the case of a perfect line, it may be of interest to conceive the following interesting fact. If a direct-current source be connected to a line of infinite length, a steady current will continuously flow into the line. The amount of current will depend upon the balance between the capacity and inductance of the line. Thus its ability to take a charge and pass it along. If we measure the voltage of the source and the current it delivers into the line, the quotient between the two gives the impedance of the load and this is called the surge impedance of the line. If we were facing four terminals in the laboratory and were told that across two of them was connected a resistance and across the other two was connected a transmission line infinitely long, with no conductor or leakage resistance, it would be a physical impossibility for us to determine by any means of measurements (direct current or radio frequency), to distinguish between them.

The surge impedance of a line without conductor or leakage resistance is the square root of the quotient between inductance and capacity for any length of the line; for a well-built line and of the dimensions conveniently used, this is sufficient for practical considerations. For a line consisting of two wires, each one-quarter of an inch in diameter and a foot or so apart, the surge impedance is of the order of six hundred ohms.

From the previous outline of the principles involved, it is evident that reflection free load of a line is obtained when the load impedance equals the surge impedance of the line as the charge will enter an impedance which is of the same value as if the line were infinitely long. The energy then is received and absorbed at the same rate as it is delivered and no reactive storage of energy takes place.

It has been found by Mr. Kroger and Mr. Lindenblad, of the Radio Corporation, that the insertion of a transmission line,

whether of natural or artificial form, is an excellent means of coupling circuits, together which, by direct magnetic or capacitive coupling, would separate into two degrees of freedom; that is, assume two tuning points.

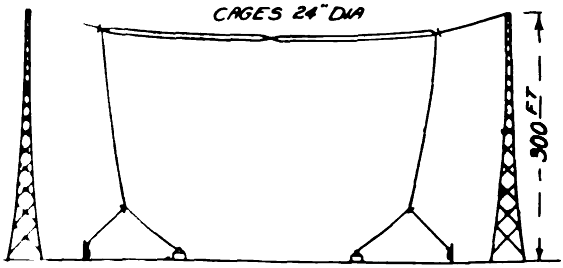
In the practical arrangement for connecting up a radio frequency transmission line, it has been found advantageous to employ transformers of high magnetizing reactance and equipped with grounded grid type shields between the primary and secondary windings. This tends to prevent uncontrollable standing waves resulting from electrostatic pick-up. Sometimes, when the field from the antenna is great in the vicinity of the line, it pays to run frequently grounded shield wires above the transmission line. It is not necessary to build a transmission line straight, as practice has proven that negligible disadvantages result from bends, provided they are not too sharp nor too frequent.

The correct impedance from the antenna loading circuit can be obtained in several ways. For instance, the secondary of the line transformer may be tapped to the point on the tuning coil which corresponds to this impedance. Another arrangement which provides a wider range of adjustments is to make the antenna tuning unit in two parallel branches and connect the secondary of the line transformer in series with one of the branches. The inductances may be varied so that the correct impedance is obtained. In adjusting a line after approximate values have been obtained from calculations and test, it is sometimes of value to insert three ammeters in series in the line, and spaced a quarter of a wavelength apart. When the three meters read alike, the line is working at the correct loading. It is readily understood that with two meters at any spacing, equal values can be obtained even if standing waves are present as the meters may accidentally be placed symmetrically in relation to the standing wave.

Antennas at the Developmental Broadcasting Station at Schenectady

The problems in connection with the design of these antennas were very different from those in connection with antennas for a commercial station. One of the main objects in connection with the Developmental Station was to compare the relative characteristics of various wavelengths from 4,000 meters to the shortest for broadcasting purposes. The antenna erected to cover the range from 4,000 to 1,000 meters is shown in Figure 16. The principles which had been found applicable to long-wave antennas

were found to be substantially correct for this antenna. The measured values of the essential characteristics checked very closely the calculated values. The antennas at the station which cover the range of wavelength from 1,000 meters to the shortest



ANTENNA No 5
RANGE 3000 TO 1000 METERS
DEVELOPMENTAL BROADCASTING STATION
SCHENECTADY, N.Y.

FIGURE 16

are of several different types and the fundamentals of these types are being established. Figure 17 shows a plan of the station

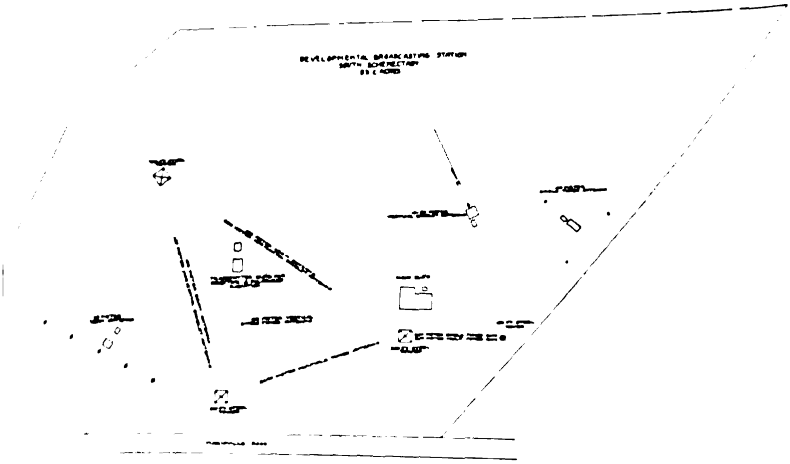


FIGURE 17—Arrangement of Buildings, Towers and Antennas, Developmental Broadcasting Station, South Schenectady

property and the location of the supports for the various antennas.

In order to determine the radiation efficiencies and directive properties of these antennas, a portable field intensity instru-

ment, Figure 18, was developed by the General Engineering Laboratory. This operates on the tube voltmeter principle. The instrument is calibrated in the laboratory in a field of known intensity. The scale readings taken in the field times a correction factor for different wavelengths, scale corrections, etc., gives directly the field intensity in microvolts per meter. Provision is made to check in the field the power factor of the resonant cir-

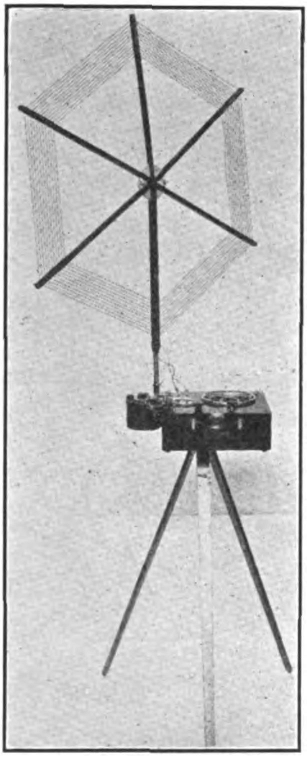


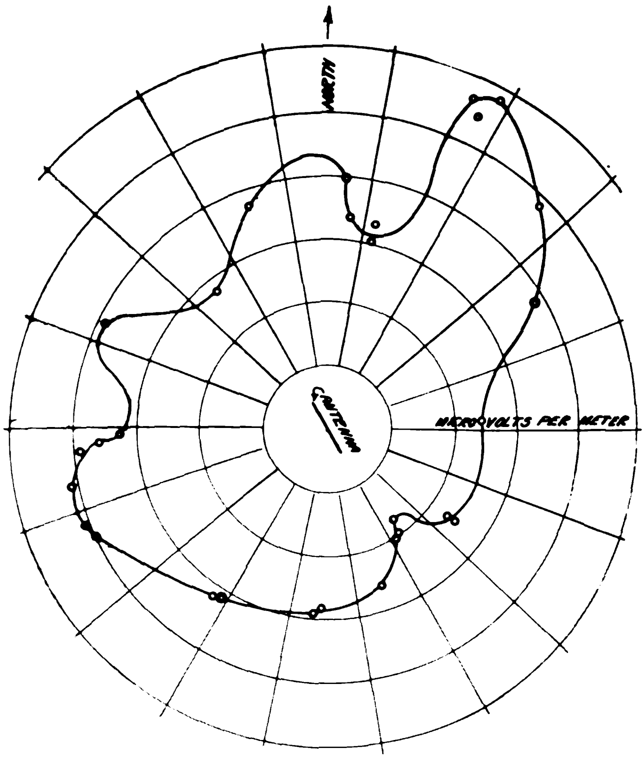
FIGURE 18

cuit, which has been found desirable when field measurements are made in adverse weather conditions. This type of instrument with suitable loop and condenser elements has been used at 1,600 380, 100 and 50 meters.

In measuring a field intensity pattern of an antenna, a contour map of the surrounding country is invaluable. Circles are drawn on the map at different radii, with the transmitting antenna in the center. The points at which roads cross these circles are chosen as the points at which field intensities are to be meas-

ured. It has been found that local conditions at the points measurements are taken influence the field intensities at those points. The most reliable measurements are made in level, open country, at least one wavelength away from power transmission lines, telephone lines, ravines or high banks, buildings, etc.

Figure 19 shows the pattern at 5 kilometers distance from the



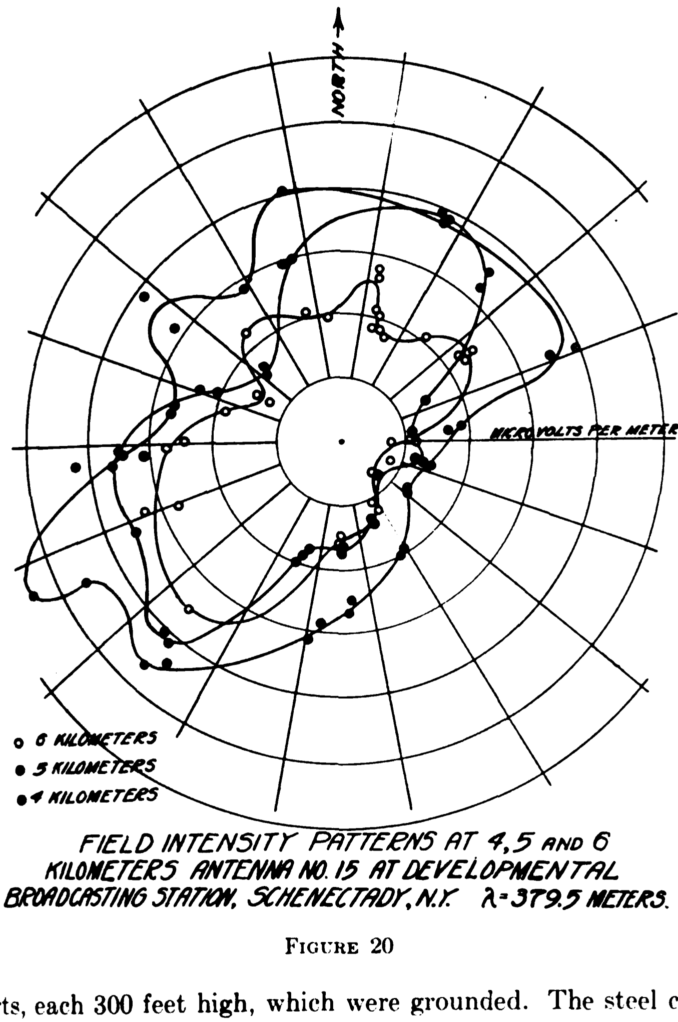
FIELD INTENSITY PATTERN AT 5 KILOMETERS
WGY ANTENNA AT SCHENECTADY, N Y
WAVELENGTH 379.5 METERS

FIGURE 19

antenna regularly used by WGY. The abrupt irregularities are largely due to local conditions at the points measurements are made. The regular pattern, as determined by several series of measurements, is slightly ellipitical with the major axis NE by SW. This is at right angles to the length of the antenna, which is multiple tuned.

Figure 20 shows a family of patterns of field intensities meas-

ured at 4, 5 and 6 kilometer distances from Antenna No. 15 at the Developmental Broadcasting Station. These patterns show the effect of local conditions on the intensities measured. The antenna was a vertical cage, operating at 380 meters. The cage was supported by a steel cable suspended between two steel sup-



FIELD INTENSITY PATTERNS AT 4,5 AND 6 KILOMETERS ANTENNA NO. 15 AT DEVELOPMENTAL BROADCASTING STATION, SCHENECTADY, N.Y. $\lambda = 379.5$ METERS.

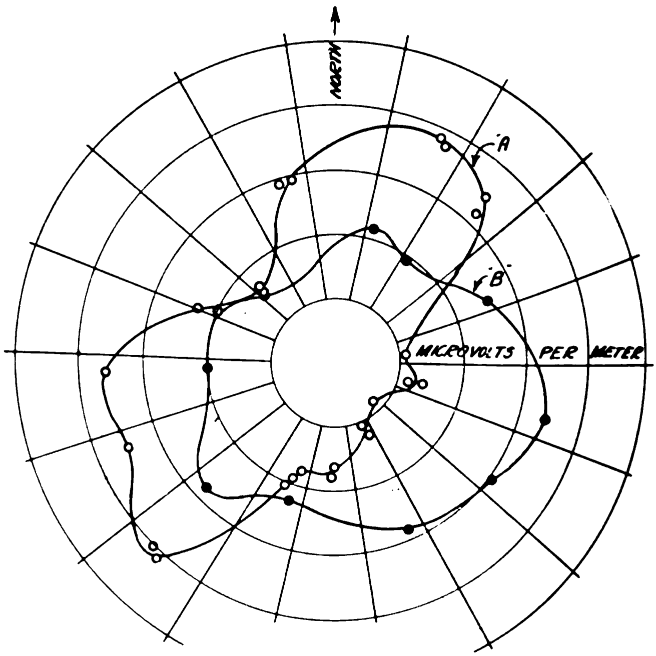
FIGURE 20

ports, each 300 feet high, which were grounded. The steel cable was sectionalized by insulators.

Figure 21, Pattern "B," shows the intensities measured at 5 km. from the same Antenna No. 15, the only essential difference being that this pattern was taken with the cage supported by non-conducting manila rope. Pattern "A" in the figure is the same as the 5-km. pattern in Figure 20. This antenna, supported

by manila rope, is one which has been used by WGY with super-power.

Figure 22 shows the pattern at 5 km. from Antenna No. 5, which is the antenna used with super-power broadcasting at



FIELD INTENSITY PATTERNS AT 5 KMS.
ANTENNA NO. 15 DEVELOPMENTAL BROADCASTING
STATION, SCHENECTADY, N. Y.
λ = 379.5 METERS.

FIGURE 21

1,560 meters. This is a multiple tuned type supported between two 300 foot grounded steel towers, shown in Figure 16.

CONCLUSIONS

This very general treatment of the complicated problems of antenna design is intended to explain how these problems are attacked and, to a large extent, have been solved. The reduction of resistance of high-power, long-wave antennas to a value considerably less than one-half ohm has introduced two problems: One pertains to a limitation of speed of signaling: the other to the increased sensitivity of tuning. The lower the resistance and

power factor of an antenna, the greater is the effect of its electrical inertia, which opposes rapid signaling. This problem is of considerable importance at the present time, and is being investigated. The tuning of an antenna having a power factor of the order of 0.0015 is so sharp that small changes in capacity, due to wind, reduce the antenna current very appreciably. An automatic antenna tuning device has been developed which maintains

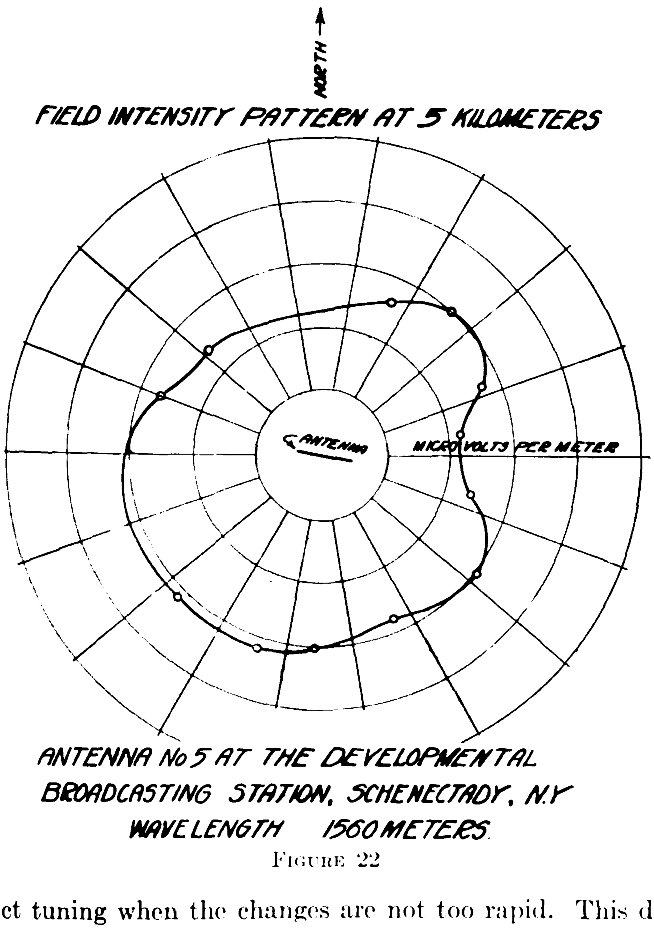


FIGURE 22

correct tuning when the changes are not too rapid. This device s being improved to operate more rapidly.

In the field of relatively small antennas which operate at powers and wavelengths suitable for marine service, broadcasting, etc., the investigations to determine how accurately the principles applied to long-wave antennas can be applied to these, are well under way at the Developmental Broadcasting Station at Schenectady.

MAINTAINING A CONSTANT READING ON AN AMMETER IN THE FILAMENT BATTERY CIRCUIT OF A THERMIONIC TRIODE*

By

E. H. W. Banner, M.Sc.,

I.—INTRODUCTION

The trouble experienced in determining what is a constant filament current is stated at length in a paper read before the Institution of Electrical Engineers (Wireless Section) on March 16, 1921.—"The Effect of Electron Emission on the Temperature of the Filament Anode of a Thermionic Valve," by G. Stead, M.A. (volume 59, page 427). Most of the speakers in the discussion emphasized the point and no satisfactory solution was arrived at. The present research was undertaken with the idea of supplying a solution to the problem.

II—An Experimental Determination of a Means of Maintaining a Constant Reading on a Filament Ammeter

If the filament of a thermionic triode is connected to a suitable supply, and the grid and anode are both insulated, an ammeter placed in any part of the circuit will read the same current. Figure 1 shows this, and two ammeters are connected, one in the positive and one in the negative lead. When the valve is in use, either oscillating or not, the filament emission causes an alteration in the two ammeter readings, the alteration depending on the method of connection of the anode circuit to the filament circuit.

Figure 2 shows one of the usual methods of connection, in which the two negatives are connected together. Through these tests the grid and anode were connected together in order to obtain a maximum emission from the filament. Figure 3 is a common alternative, showing the anode battery negative connected to the filament battery positive.

It is found that on switching on the anode battery the reading

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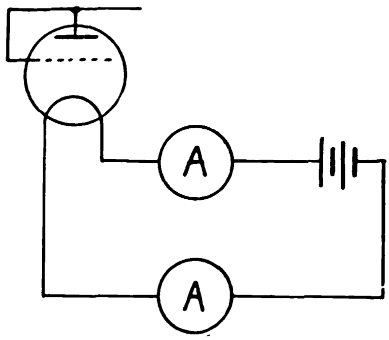

FIGURE 1

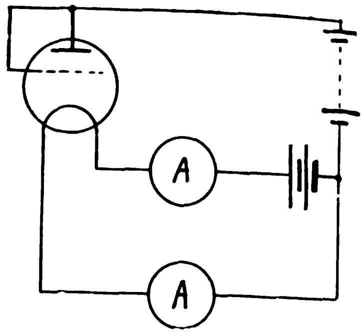

FIGURE 2

of the negative ammeter increases and the positive decreases for both the above methods of connection. Figure 4 is similar to Figure 3 except that the connection is made to the filament side of the ammeter. In this case both readings increase. Lastly, Figure 5 shows the anode battery connected to the filament side of the negative ammeter. Now both readings decrease on switching on the anode battery.

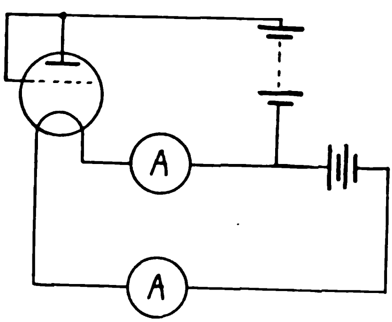

FIGURE 3

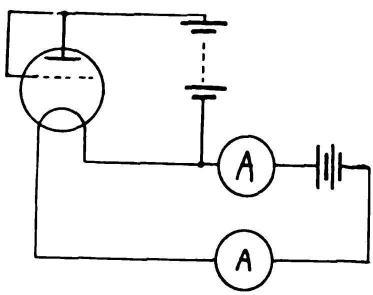

FIGURE 4

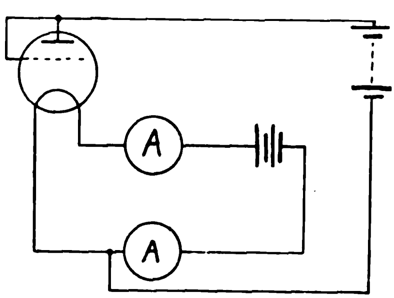

FIGURE 5

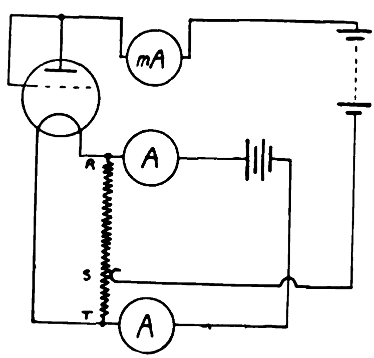

FIGURE 6

This states the case as generally accepted, that the switching on of the anode battery makes it impossible to maintain the filament current constant, and a statement that the filament current was constant during any particular test is void unless the method of connection and the position of the ammeter are stated, at any rate for accurate work.

This investigation was commenced with the object of finding if any position of the ammeter, and a method of connecting the anode battery, was possible, so that the ammeter reading would be unaffected by any variation in the anode circuit.

TABLE I.

Figure	2	Negative ammeter reading increases.	Positive decreases
	3	Negative ammeter reading increases.	Positive decreases
	4	Negative ammeter reading increases.	Positive increases
	5	Negative ammeter reading decreases.	Positive decreases

Comparing the cases shown in Figuers 4 and 5, it is seen that the two extremes are met, and it appeared possible to obtain a mean position between these cases so that both ammeter readings would be constant.

The circuit of Figure 6 was then wired up, using a slide potentiometer-rheostat RT with a tapping at S variable between R and T. When S is at R, Figure 4 is reproduced, and when at T, Figure 5.

A test was then commenced to endeavor to find a position for S so that an ammeter in the circuit would indicate a steady amount. As the anode current for these tests was about 7 milliamperes and the filament current about 0.7 ampere the effect of adding the two is to increase the current from about 0.700 to 0.707 ampere, an increase of 1 percent. This is a small proportion and the usual forms of measuring instrument are too insensitive to indicate a change much less than about 1 percent with ease. In order to be able to state that the filament current is constant it is therefore not sufficient to state that the ammeter reading is constant as a change of 1 milliampere is not shown, and it is necessary to detect a smaller quantity than this in order to state that the current is constant.

It will be seen, therefore, that it is necessary to be able to read a change in current at least of the order of 0.11 percent or 1 in 1,000. No indicating instrument that will read this was available, and so as an indicator a reflecting galvanometer was arranged to project its light spot on to a wall about two meters from the mirror. The terminals were short-circuited by a piece of bare copper wire, the actual length being adjusted by trial. For the test

the circuit of Figure 6 included the short-circuited galvanometer in series with one of the ammeters. It must be noted that the galvanometer deflection was not used for measuring current, but only for detecting a change of current. The galvanometer, in effect, is used as in a null test, the steady filament current merely displacing the zero. In this way the various instrument errors are eliminated. The short-circuit was adjusted to give a steady deflection of about two meters on the scale, or rather on the wall, as the galvanometer had been moved back from its normal position to about two meters, and the deflection was off the usual scale. The other ammeters in circuit were only used for approximate readings, as nothing better than a first-grade instrument was available for current measurement in the author's laboratory. The filament was then switched on to a 4-volt accumulator and when the light spot had come to rest, the anode battery was switched on. When the slider was near the negative end, the deflection decreased and when at the other end, an increase was observed. This only confirmed the preliminary rough tests. The slider was adjusted until on switching on the anode battery no change of deflection occurred. It was possible to read a change of 1 millimeter, and as the deflection was two meters, the sensitiveness was of the order of one in 2,000, which is within the limit attempted (1 in 1,000). This means that with the slider at the point found, the change of current for a filament current of 0.7 ampere was not greater than 1 in 2,000×0.7 or 0.35 milliampere. With an even more sensitive arrangement the point of balance might be found still closer, if desired, but the change is very small in the region of no deflection and so a slight alteration in the slider position is negligible.

It was then necessary to find the position of the slider with respect to the filament battery, and so the ratio $\frac{S\ T}{R\ T}$ was measured. This was found to be 0.17, or practically $\frac{1}{6}$. (A later test with a ratio of $\frac{1}{6}$ proved satisfactory.) It was not obvious if this ratio would prove to be constant under different conditions, and so two further tests were carried out. The anode battery voltage was reduced to about half the previous value, other conditions remaining constant. No change in the deflections was observed. Secondly, a reduced filament current was used and finally a different valve. The spot showed no change on switching the anode battery on and off in each case, showing that the ratio of $\frac{1}{6}$ was sat-

isfactory and constant for different conditions of the circuit.

The first test was repeated with the galvanometer in the other lead, and similar results were obtained, as was expected from a study of Figure 6 as the two ammeters are in series with no branch circuits between them and the battery.

III—An Investigation Into the Distribution of Current in a Triode Circuit

As a further check it was considered desirable to check the currents all round the circuit, and as the author's laboratory was limited in its stock of instruments, the work was concluded at the University of Birmingham with permission of Professor W. Cramp.

The triode was connected up as Figure 7, ammeters being placed in each filament lead and in each battery lead. With the circuit RT broken, the four ammeters $A1$, $A2$, $A3$, and $A4$ were in series and their readings were taken for different values of current in order to calibrate the remainder against $A1$, which was known to be the most accurate.

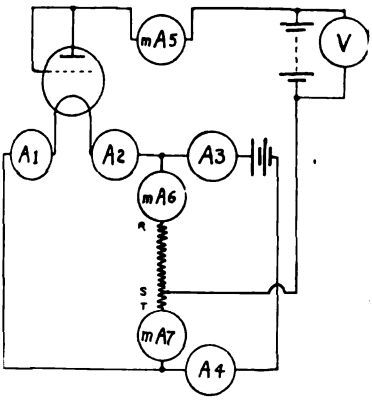

Figure 7

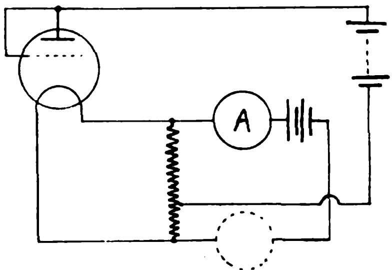

Figure 8

The milliammeter in $A5$ read the emission current and was in series with the anode battery. Milliammeters $mA6$ and $mA7$ read the steady current thru the resistance RT when the anode battery was disconnected. Finally, an electrostatic voltmeter read the anode battery voltage.

Readings were taken on all instruments under the following conditions:—

(1) Filament Circuit only made.

(2) Filament and resistance RT connected.

(3) As (2) with the anode battery on.

(4) As (3) but with ratio changed to $\frac{1}{5}$.

(5) As (3) but with ratio changed to $\frac{1}{7}$.

(6) Tests (2) and (3) with a 6-volt battery and rheostat.

(7) Tests (2) and (3) with reduced filament current.

(8) Tests (2) and (3) with a reduced anode voltage.

The first three tests are the important ones, and a summary of their readings, corrected for instrument errors, is given in Table 2.

TABLE 2

Test—Instrument Readings

Test	*A*1	*A*4	*A*2	*A*3	*mA*6	*mA*7	*mA*5	*V*
(1).......	0 670	0 670	0 670	0 670				
(2).......	0 670	0 676	0 670	0 676	6 52	6 52		
(3).......	0.672	0.676	0 666	0.676	7.53	1.26	6.39	82.5

and $\begin{cases} A1 \text{ and } A2 \text{ are Filament Ammeters} \\ A3 \text{ and } A4 \text{ are Battery Ammeters} \\ A2 \text{ and } A3 \text{ are Positive} \\ A1 \text{ and } A4 \text{ are Negative} \end{cases}$

Readings for the subsequent tests are given in Table 3.

TABLE 3

Test	*A*1	*A*4	*A*2	*A*3	*mA*6	*mA*7	*mA*5	*V*
(4).......	0 671	0 676	0 665	0 676	9 00	2 88	6 09	81.0
(5).......	0.674	0.676	0.668	0.676	6.45	0 35	6 09	81.0

(6) No change

(7) *A*1 reduced to 0.400 Ampere. No change.

(8) *V* reduced to 47.0 Volts. No change.

Observations

In test (1) all four ammeters read the same, when corrected for instrument errors, as expected. In test (2) the readings of the battery ammeters increased slightly owing to the current in *RT*. Very careful observation was necessary to detect the change, which was less than 1 percent of the reading. The current through *RT*, as read on *mA*6 and *mA*7 was the same.

Test (3) confirmed roughly the result obtained in the first part of the research, that is, that the battery ammeters maintained a constant reading when the anode battery was switched on. It further showed that the distribution of current thru *RT* was altered on connecting at the point *S*. Tests (4) and (5) were

further confirmations of the experimental result found earlier, that the ratio $\frac{S\,T}{R\,T}$ should be $\frac{1}{6}$. Test (6), using a 6-volt battery and a rheostat in series to maintain $A\,1$ constant as before, showed no change from test (3). For test (7) the current as read on $A\,1$ was reduced and again no change ensued on $A\,3$ and $A\,4$.

Finally test (8) showed that the ratio is independent of the anode voltage used. This may be summarized as follows:

When an ammeter is connected in either battery lead and the anode battery is connected as shown in Figure 7, no change in the ammeter reading occurs after switching on the anode voltage with

(1) Different filament battery voltage.

(2) Different filament current.

(3) Different anode voltage.

The actual resistance of RT may be varied provided the ratio is constant. In the first tests it was 850 ohms, and in the latter 600 ohms. It should be high in order to reduce the loss of power in it and to make the battery ammeter read as little as possible more than that used in the filament-anode circuit. If the resistance is too high, it is possible that the unequal currents at each end may heat up the resistance sufficiently to alter the ratio. This is not likely if the resistance is of the order of a thousand ohms and made of wire, not a carbon line. Figure 8 shows the final connections using one ammeter only. This may be in either the positive or the negative lead, as shown.

SUMMARY: The distribution of current along the filament of a thermionic valve is not constant on account of the emission which takes place from the filament to the anode.

When the valve is not emitting, ammeters in each filament lead read the same value, but when emitting they are necessarily different, and for the usual methods of connection between the anode battery and filament they are also both different from the non-emitting reading.

For accurate tests it is necessary to have a constant reading for comparative tests, and as the filament current cannot be maintained constant, a circuit has been devised in which there is no change on either ammeter reading when the anode battery is switched on.

This is the filament battery current, which, when constant for the cases of non-emitting and emitting, provides a standard for comparison between different tests.

PORTABLE RECEIVING SETS FOR MEASURING FIELD STRENGTHS AT BROADCASTING FREQUENCIES*

By

Axel G. Jensen

(Bell Telephone Laboratories, Incorporated, New York)

In a paper by Bown, Englund and Friis on "Radio Transmission Measurements,"† there are described several different methods of measuring radio signals and some of the sets for making these measurements are described in detail. The rapid growth and the increasing importance of radio broadcasting has since made it desirable to construct an improved form of measurement set for use in the field, and the purpose of the present paper is to describe such a set which has recently been developed in the Bell Telephone Laboratories and which is now being used by the American Telephone and Telegraph Company for field strength surveys, etc. A portable measurement set for this type of work was in fact described in the above-mentioned paper and several sets of this type have been in use for the last couple of years, but in order to emphasize the improvements made in the latest type of measurement set there is given, in the following, a very short description of this first portable set. The set itself is shown in Figure 1 and a schematic diagram is given in Figure 2.

The receiving set unit is a double detection set provided with a sensitive meter in the plate circuit of the low frequency detector and the first part of a measurement consists in tuning in the signal to be measured and adjusting the gain of the receiving set so as to obtain a suitable signal reading on the detector meter. Next, the local signal oscillator is started and adjusted to the same frequency as that of the signal by zero beating, after which the loop is cut out of the circuit and the input shunt adjusted so as to give the same meter deflection as before, which means that the local signal voltage impressed upon the grid of the high frequency detector is the same as the voltage across half the loop

†Proceedings of The Institute of Radio Engineers, Volume 11, number 2, April, 1923.

*Received by the Editor, March 15, 1926. Presented at a meeting of the Institute of Radio Engineers, New York, April 7, 1926.

is equal to the voltage across
as measured by a tube
own ratio of the shunt;
the step-up ratio of the loop
the loop by the signal. The

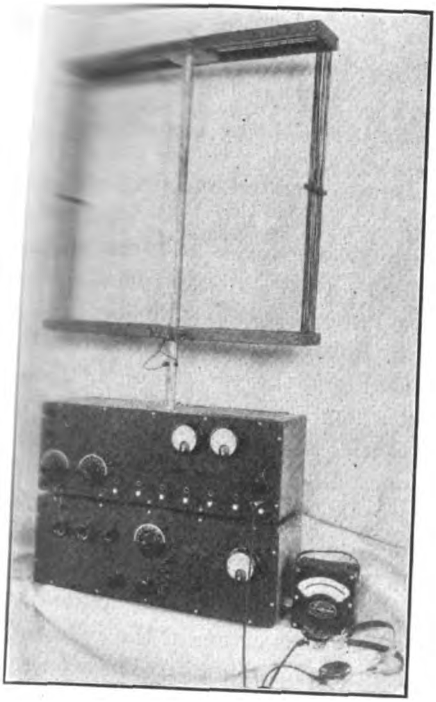

FIGURE 1—Early Model of Portable Field Strength Measuring Set for Wavelengths from 200 to 500 Meters

atio of the loop is given by the ratio of ωL over R, in which L the inductance and R the resistance of the loop. This ratio thus a measure of the resonance effect of the loop, giving the voltage E across the loop at resonance as $\omega L/R$ times the voltage induced in the loop. This loop voltage e gives the field strength on division by the effective height of the loop. The effective height of the loop is a function of its geometrical proportions and the frequency, and may be determined once for all. The calibration of the tube voltmeter will stay constant for a considerable time, but the determination of the loop step-up is inconvenient, especially in a set intended for field use. In order to find the loop-

step-up it is necessary to determine the distributed capacity and the inductance of the loop, and the resistance of the loop as a function of the frequency. The first two quantities will remain

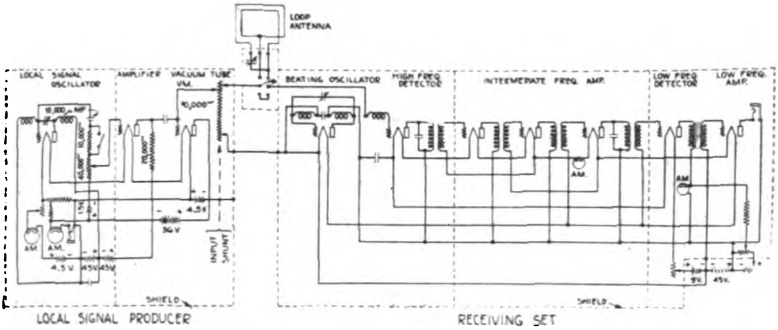

FIGURE 2—Schematic Circuit Diagram of the Set Shown in Figure 1

practically constant for any given loop, and the resistance of the loop will remain sufficiently constant for a considerable

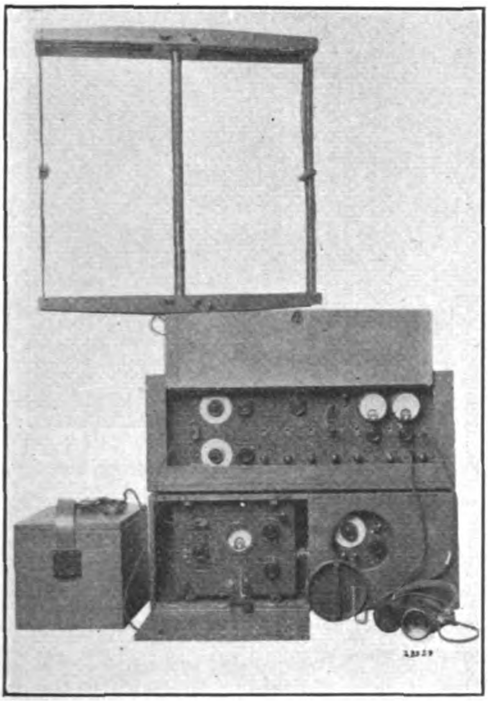

FIGURE 3—Latest Type of Portable Field Strength Measuring Set

length of time, as long as the set is used only in the laboratory and is not exposed to the weather. In a set for field use, however, it has been found that the loop resistance changes considerably with the weather, so that in order to avoid errors it is necessary to measure this resistance several times a day during the use of the set, especially under bad weather conditions. This is, of course, very inconvenient and causes quite a loss of time, and the main problem in designing the new measurement set has, therefore, been to develop a method by means of which this calibration of the loop might be avoided.

FIGURE 4—Field Strength Measuring Set in Operating Condition in the Field

Such a method, already in use for several years, is described in connection with measurement sets for long wave length in the paper mentioned above, and it was decided to try to adapt this method to shorter waves also.

In doing this it was necessary to modify the input circuit somewhat in order to make the set more compact and also in order to avoid "pick-up" at these higher frequencies, but the gen-

eral principle is the same as that used in the earlier long wave measurement sets referred to.

The set is shown in operating condition in Figures 3 and 4 and details of the set are shown in Figures 5, 6, 7 and 8, while Figure 9 gives a schematic diagram of the entire set. Referring to this diagram it is seen that, as before, the receiving set is in principle a double detection set provided with a microammeter normally connected in the plate circuit of the low frequency detector and used for indicating the signal received. This meter may, however, also be used for testing the plate current of any of the other tubes by inserting a patch-cord between the meter jack and the plate circuit jack for the tube in question. Also a separate jack marked "meter" is provided for plugging in an external instrument instead of the meter permanently mounted in the set. The plug marked "stage shifter" is always inserted in one of the three jacks, 1, 2 or 3 when the set is in use, the corresponding number of stages of intermediate frequency amplification in operation being 1, 2 and 3, respectively. Finer variations in the gain of the set are obtained by varying the value of the resistance marked "gain control," which is shunted across one of the intermediate frequency transformers. The oscillator coil is wound in toroidal form in order to prevent any direct coupling between the coil and the loop, as such coupling would result in a beating oscillator voltage, impressed upon the grid of the high frequency detector, which would vary with the position of the loop, thereby making the measurements inaccurate.

The potentiometer shown in the diagram directly under the plate current meter is used for balancing out the initial plate current of the low frequency detector, in order that the entire scale of the meter may be made useful for indicating the increase in current due to a signal impressed upon the grid of the detector tube.

The power supply for the filament and plate circuit of the receiving set is a dry cell combination contained in a special battery box, which may be seen in the left part of Figure 3. From the same figure it will be seen that the loop is made with flexible wire and is collapsible in order to facilitate transportation.

A patch-cord is used for connecting the middle terminals of the loop to the terminals on the input box, thereby closing the loop circuit through a known resistance of normally one ohm. This resistance is located in the input box and is further described below in connection with the input potentiometer.

The local signal equipment is shown in the lower part of the

diagram in Figure 9, and consists of two separate units, namely, the oscillator unit and the input unit. The input unit is contained in a metal box shown in the left half of the lower box in Figure 3, and the oscillator is contained in a similar metal box, part of which may be seen in the same figure through the hole in the right half of the lower box.

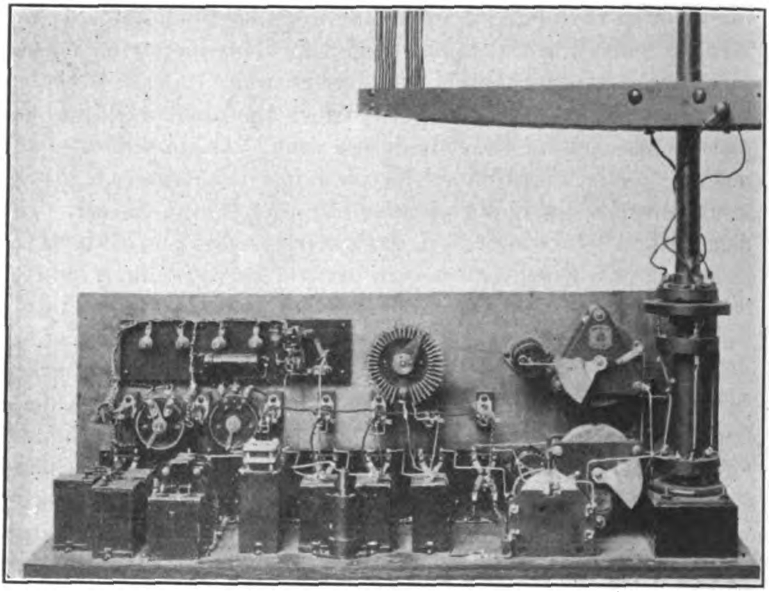

FIGURE 5—Rear View of Receiving Unit

During an actual measurement this hole is tightly closed by a metal cover, ground to fit, thus completely closing an outer metal box formed by a heavy copper lining on the inside of the compartment containing the oscillator box. The leads from the input unit to the oscillator unit are enclosed in a heavy copper tube connecting the input box with the outer box of the oscillator unit and are connected to the two terminals shown on the oscillator panel. The inner oscillator box is mounted insulated in the outer box and is connected to this only at one point, namely through one of the two leads connecting the input unit and the oscillator unit, this lead forming a direct connection from the inner oscillator box to the input box and thus, through the copper tube, back to the outer oscillator box.

This double shielding of the oscillator unit is absolutely essential in order to avoid any direct "pick-up" from the local signal

oscillator by the loop. Without careful shielding this "pick-up" voltage may easily be larger than the voltage to be measured, thus making the measurements worthless. The oscillator coil is, of course, also wound in toroidal form in order to make its external field as small as possible, and the power supply for the oscillator consists of dry cells contained in the oscillator box itself, since any outside battery connections would increase the "pick-up" considerably. This is shown in Figure 6.

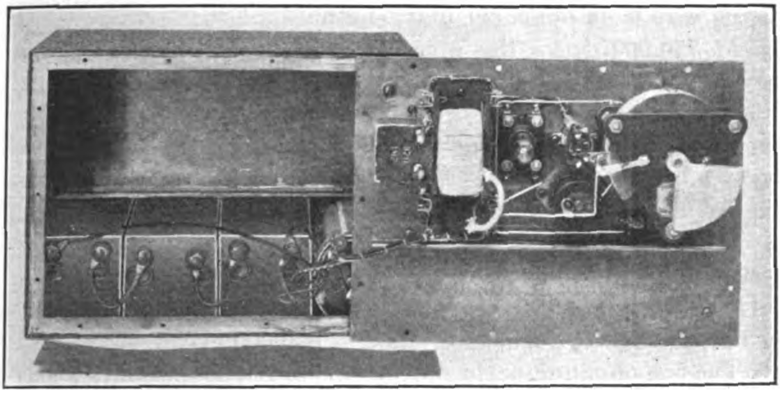

FIGURE 6—Interior View of Local Signal Oscillator Unit

The oscillator is of the Hartley type and the input current is obtained by shunting a high resistance R across a small part of the oscillator coil and then tapping across part of the resistance. The current then passes through a smaller resistance r, used for fine adjustment, next through a sensitive thermocouple Th and finally through the attenuator or current dividing potentiometer P.[1]

The values of the resistance in the different units of this potentiometer are given in the diagram, and the units are wound non-inductively (reverse loop-winding) on a hard rubber toroid so that the points a and e are close together and the points e and c directly opposite on the toroid, thereby reducing the length of the connecting wires $a\ b\ e$ and $c\ d\ e$ to a minimum.

The capacity of such a non-inductive winding is small and the inductance may be calculated by the following formula[2]

$$L = 2l\,(\log_e d/p + 1/4 - A)$$

[1] A description of this potentiometer has already been published in a short note on "Potentiometer Arrangement for Measuring Microvoltages at Radio Frequencies," Phys. Rev. Volume 26, number 1, page 00 July, 1925.

[2] See E. B. Rosa, Bull. Bur. Stand. 4,301 (1907-8).

in which l is the total length of wire, p the radius of wire, d the distance between adjacent turns, and A a constant varying from 0 to 0.45 as the number of turns varies from 0 to infinity. The value of A is 0.25 for a coil of four turns, and it will therefore be safe to disregard the two last terms in the formula, since all the coils in the potentiometer have more than four turns. Applying this formula to the coarsest wire used in the potentiometer, namely No. 36 B & S Advance wire, DSC, we get $d/p = 3.5$ and thus an inductance of 2.45 cm. per unit length, while the resistance of the wire is 30 ohms per unit length.

At 750,000 cycles this gives an inductive drop which is 3.5 percent of the resistance drop and thus an impedance which is equal to $\sqrt{1^2 + 0.035^2}$, or 1.0006 times the pure resistance of the wire. It will, therefore, be seen that the impedance will not be as much as one percent higher than the pure resistance until the frequency is increased to about 3,000,000 cycles.

For the finer wire the relative excess of inductive drop over resistance drop will be still smaller, so that the entire potentiometer will attenuate the current with an accuracy of one percent or better up to frequencies of about 3,000,000 cycles.

The one ohm unit in the output side of the potentiometer consists of a piece of No. 36 manganin wire approximately 3.5 cm. in length and arranged bifilar so that we may use the same formula as before in calculating the inductance. We have here $A = 0$ and d/p approximately 5, so that $L = 13$ cm. and $\omega L = .06$ ohm at 750,000 cycles. The resulting impedance is thus approximately 1.002 ohm or only 1/5 percent higher than the pure resistance.

The highest current attenuation is obtained with the movable arm of the potentiometer at point f, in which case the output current i is one ten-thousandths of the input current I, and since the thermocouple combination used will measure one milliampere conveniently it is possible to determine voltages down to about 1/10 microvolt with an accuracy of one percent or better.

The following ratios of i/I can be obtained by this potentiometer: .0001; .0002; .0005; .001; .002; .005; 01; .02; .05; .1; .2; .5 and 1.0, and intermediate values of the voltage across the one ohm unit may be obtained by varying the current I. These different ratios were checked, step by step at 750,000 cycles, by using the low-frequency detector in the receiving set as a calibrated tube voltmeter, and in no case was the discrepancy between the calculated value and the measured value found to be more than one percent.

This check shows, at the same time, that direct "pick-up" from the input oscillator to the loop has actually been eliminated.[8] The potentiometer, including the switch, is contained in a separate compartment of the input box, as will be seen from Figure 7, and the potentiometer itself is again enclosed in a separate copper can, which has been removed in Figure 8 in order to show the hard rubber toroid itself. Thus the resistance units are shielded from the switch parts and the one ohm unit in the output is shielded from the rest of the potentiometer. This one ohm unit may be seen in Figure 7 and is connected to the terminals on the panel through a pair of twisted wires. All these precautions in regard to shielding have been found necessary in order to prevent any stray couplings between the different parts of the circuit.

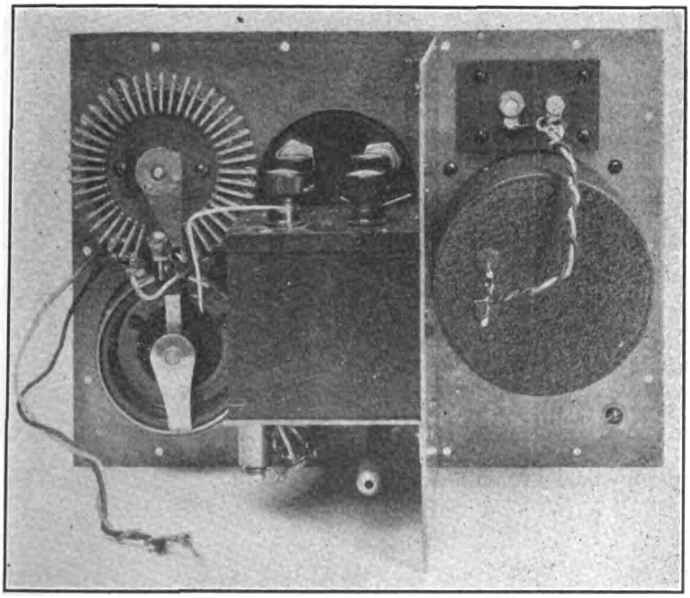

FIGURE 7—Interior View of Input Box Unit

A field strength measurement may now be obtained as follows: First the signal is tuned in on the receiving set and the gain of the set is adjusted so as to give a suitable reading on the detector meter; next the local signal oscillator is started and by zero

[8] The increase in resistance due to skin effect is absolutely negligible for the frequencies in question here. Not until the frequency is raised to 15 to 20 million cycles does this increase amount to one percent even for the coarsest wire used in the potentiometer.

beating tuned to the same frequency as that of the signal. Care should be taken here to make sure that the local signal oscillator is not zero beating with some stray signal or with the beating oscillator, and it is found convenient in this connection to watch the detector meter while adjusting the frequency of the local oscillator. When the beat note between the oscillator and the signal becomes very low, *i. e.*, below audibility, the needle on the meter will start moving up and down the scale as the two frequencies pull in and out of phase, thus indicating that the oscillator is being adjusted to the right frequency.

Of course, during this adjustment the input current from the oscillator should be kept low enough so as not to cause any excessive current to flow through the detector meter. The

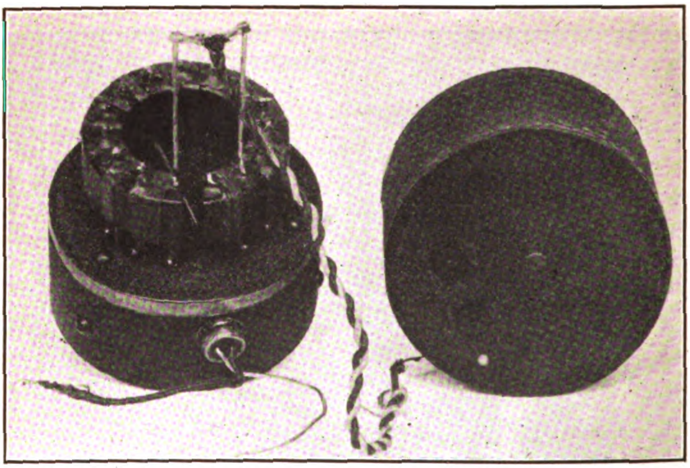

FIGURE 8—Input Potentiometer with Cover Removed, Showing Toroidal Arrangement of Resistance Units

meter deflection is then read, with the local oscillator stopped, after which the loop is turned to minimum position, to eliminate the signal and, lastly, the input current and the attenuating potentiometer are adjusted to give the same deflection on the detector meter as before. We then have an equality between the voltage drop across the one ohm resistance and the voltage induced in the loop by the incoming signal. With a thermocouple current of I amperes and a current ratio $a = i/I$, we thus have for this voltage:

$$e = a \times I \qquad \textit{volts}$$

If the area of the loop is $A\ cm^2$ and the number of turns N, we have for the effective height of the loop:

$$h = \frac{1}{3} \times 10^{-10} \times 2\pi f \times A \times N \qquad cm.$$

f being the frequency of the inductance signal, and the field strength is thus given by:

$$E = \frac{e}{h} = \frac{3 \times a \times I \times 10^{10}}{2\pi f \times A \times N} \qquad volts/cm.$$

or, if we measure the input current I in milliamperes, the frequency in kilocycles and the field in microvolts per meter:

$$E = \frac{a \times I}{f} \times \frac{3 \times 10^{12}}{2\pi \times A \times N} = k \times \frac{a \times I}{f} \qquad microvolts/meter$$

The constant k may be calculated once for all for a particular loop, and the attenuation a is read directly on the potentiometer, so that the only calibrations necessary are a current calibration for the thermocouple and a frequency calibration for the loop condenser or the local signal oscillator condenser. Both calibrations will hold for extended periods, provided the set is not abused or the thermocouple overloaded.

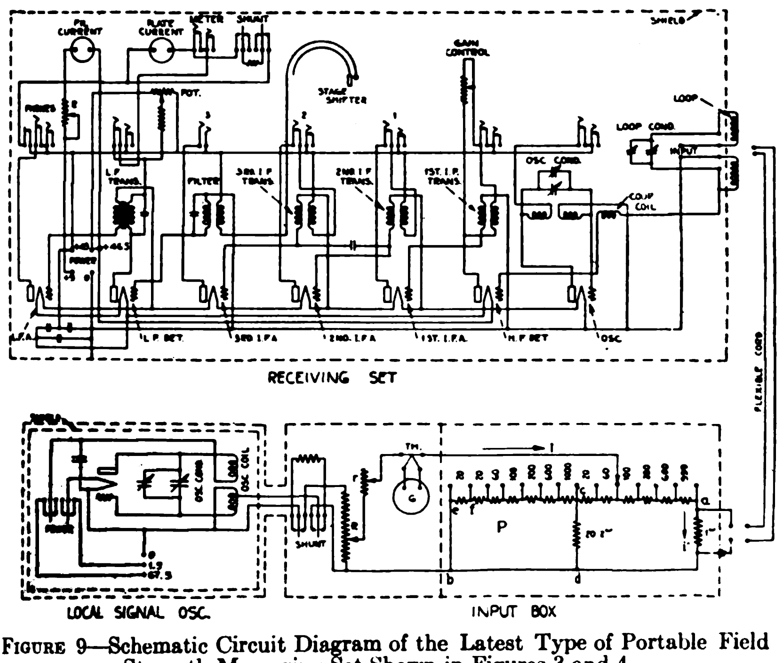

Figure 9—Schematic Circuit Diagram of the Latest Type of Portable Field Strength Measuring Set Shown in Figures 3 and 4

The set in its present form has a field intensity range of about 30,000 to 20 microvolts per meter and a frequency range of approximately 600 to 1,200 kilocycles (500-250). This range may be extended upward to about 150,000-200,000 microvolts per meter by increasing the resistance unit in the output side of the potentiometer correspondingly. A too large value of this resistance will make the potentiometer inaccurate unless the 999 ohms unit is changed also. It would be comparatively easy to extend also the wave length range both ways by making interchangeable oscillator coils, but the potentiometer will not be accurate for frequencies much greater than 1,500 kilocycles (200 meters). It was shown above that the impedance of the one ohm unit at 750 kilocycles (400 meters) is 1/5 percent higher than the direct current resistance; at 1,500 kilocycles (200 meters) this difference will be found to be 1 percent, and at 7,500 kilocycles (40 meters) it has increased to 17 percent. At this latter frequency the impedance of the smallest unit in the potentiometer itself (No. 36 wire) will be about 6 percent higher than direct current resistance, and it is thus seen that the set cannot be used for these high frequencies without making a special frequency calibration of the potentiometer. Furthermore, at such high frequencies great care must be taken to make the switch parts and other metal parts of the potentiometer as small as possible in order to minimize shunt capacities to ground, which would make the current flowing through the potentiometer smaller than the current measured by the thermocouple. Of course, none of these objections arise in extending the range to frequencies below 600 kilocycles.

SOURCES OF "A," "B" AND "C" POWER FOR RADIO RECEIVERS*

By

Walter E. Holland

Introductory

The purpose of this paper is to describe the various present-day sources of "A," "B" and "C" power for the operation of radio receivers and to indicate the advantages and disadvantages of each. It is too early for anyone to predict which of these sources will prove fittest ultimately and will come into most general use. It is the writer's opinion that as long as the three-element vacuum tube remains the basis of radio there will continue to be substantial fields for storage batteries and dry batteries as well as for battery substitute devices. Considerations of performance, practicability and cost will define the rightful fields of each in time. It is hoped this paper may help clear the ground so that each kind of power source may find its rightful application.

"A" Power Sources

The storage battery, at first, was the only satisfactory source of current for filament heating, and as a 6-volt battery was called for it it is but natural that standard automobile starting-and-lighting batteries were used. These batteries are necessarily made with comparatively thin plates and plate insulators that they may be capable of delivering the high discharge currents needed to crank automobile engines. They were not designed for stationary use at low discharge rates and no special means to prevent spray coming out was provided or thought necessary. Such batteries were soon found to be generally unsuitable for radio use in the home.

It will be a surprise to some to hear that the low-rate discharging and stationary use of batteries in radio "A" service are more wearing to the plates and harder on the battery than the high-rate discharging and vibration to which a starting battery is subjected. The low-rate discharging, especially when inter-

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mittent, allows time for the electrolyte to diffuse in the plates so that relatively great useful ampere-hour capacity is developed and the active material of the plates is worked to a considerable depth instead of just at the surface. Each time the positive active material discharges to lead sulphate and is subsequently charged back to lead peroxide, the coherency of the active material structure is weakened and the active material is softened, resulting eventually in a breaking up into non-coherent particles. The depth or amount of active material that is thus softened is directly proportional to the number of ampere-hours taken out of the battery on each discharge. At the high discharge rates of engine-cranking service a battery will deliver only a small fraction of the ampere-hour capacity that is actually present in the charged plates in the form of potential chemical energy and that can be realized on low-rate intermittent discharge. It will thus be seen that a battery is self-protecting at high discharge rates, whereas at low discharge rates it can be drained of its energy even to the point of injury. The high discharge rates of automobile service work only a very thin layer of active material at the surface of the plates and normally the operation of the car keeps the battery close to the point of full charge all the time, which is good for the battery, provided it is not excessively overcharged at high rates. The vibration in automobile service is also good for the battery as it helps the plates to free themselves of any short-circuits which tend to form across the plate edges by accumulation of active material particles.

Quite early the necessity for thick plates and thick plate insulators or separators in radio "A" batteries was seen and improved types having the general appearance of automobile batteries, were produced. Figure 1 shows a typical "A" battery of this kind as made today.

The thick plates are spaced and insulated with specially prepared thick ribbed-wood separators and between the ribbed side of each separator and the face of the adjacent positive plate is placed a slotted hard-rubber retainer. The function of this hard-rubber retainer is to hold the softened lead peroxide active material in place on the plate and protect the wood from the harmful action of this strong oxidizer. Instead of the old combination of wood case and individual rubber jars, a strong, clean hard-rubber container, molded in one piece with three compartments, is used. Molded hard-rubber covers close the tops of the compartments and these are usually sealed in the container with

a special elastic sealing compound and at the cell posts with soft rubber gaskets so mounted as to be held under compression. The cells are connected in series by means of alloy-lead connectors, integrally welded to the posts, and convenient terminals are provided at the open posts of the end cells. Each cell is provided with a chambered vent cap which is removable when rotated a quarter turn.

FIGURE 1—Radio "A" Battery with Charge Tester

The battery shown in Figure 1 is equipped with a charge tester which is built into one of the vent caps. This charge tester consists of a small ball-type hydrometer which, when the rubber bulb at the top is squeezed and released, will indicate by the floating or sinking of the two wax balls of different densities the approximate extent to which the battery is charged or discharged. The tip of the charge tester extends into the battery to the minimum normal electrolyte level so that the tester also serves as a level indicator. If no solution is drawn up into the barrel of the tester when the bulb is squeezed and released, it is at once apparant that the solution level is low and water is needed. The particular merit of this form of tester lies in its convenience and the fact that it does away with the danger of acid dripping where it may do injury, which is always present with the conventional type of hydrometer.

The battery is equipped with a bail handle for convenience in carrying because, in spite of the greater convenience of charging at home and the simplicity and cheapness of present-day chargers, the fact remains that for one reason or another, a large number of users still carry out their batteries for charging.

With a well-designed vent cap and ample gas space above the electrolyte level, this conventional type of battery will keep quite clean and dry externally provided it is charged at suitable charging rates. Batteries of 120 ampere-hours capacity or larger may be safely charged with a 5-ampere charger, but the more common batteries of 50 to 100 ampere-hours capacity should be charged with a 2-ampere charger to give the greatest satisfaction. It is to be deplored that certain charger manufacturers are spending their advertising money in an effort to tell people that 2-ampere chargers are out of date and that rapid charging is desirable. Experience has shown the great advantage of slow charging as a means of preventing spray, extending the time a battery will operate without needing water and prolonging battery life. A 2-ampere charger is adequate to satisfy the needs of the vast majority of broadcast listeners; it is cheaper to buy and to maintain, and, in general, will prove more satisfactory in use than a 5-ampere charger.

Battery and charger manufacturers have for some time advocated the use of switches or plugs and sockets permanently wired to the battery charger and radio set as a very convenient method of operating with batteries. Some manufacturers list suitable switches or plugs and sockets for making these permanent hook-ups. With such an arrangement the charging of a battery is reduced to the mere throwing of a switch or moving of a plug. Charging then becomes so easy that most users prefer to keep the battery well charged by charging frequently. The need for large capacity per discharge then disappears. This has led to the development of small "A" batteries having improved features which were impracticable in the larger batteries. Chief among these features is the use of a transparent container, molded out of glass, which makes possible the use of a built-in charge indicator and high and low solution level lines. Figure 2 shows the construction of a 6-volt battery of this type.

The three cells of this battery are mounted in separate compartments of the one-piece pressed-glass container. The positive plates and the interior negative plates of each cell are mounted in pairs while the outside negative plates are mounted singly. This makes a balanced plate construction in which there are the same number of individual positive plates and negative plates per cell. By mounting the inner plates in pairs, the life advantages of exceptionally thick plate construction are realized and the number of plate separators is reduced to the minimum so that the thickness of each may be made very great. The plates

are suspended from the molded hard rubber cover which rests on ledges molded in the jar walls. This does away with the necessity for ribs or plate rests in the bottom of the jar and makes it possible to use separators which extend well below the bottom of the plates and rest on the bottom of the container.

FIGURE 2—Radio "A" Battery with Built-in Charge Indicator

The vertical edges of the positive and negative plates respectively are staggered or offset with respect to each other, while the width of the separators is such as to fill up the full width of the compartment after they have become expanded by the wetting with electrolyte. The very thick separators reaching to the bottom of the cell and extending beyond the staggered vertical edges and above the tops of the plates provide exceptional security against the possibility of short-circuiting at the plate edges, due to "mossing" or "treeing" of the active material.

Each cover is provided with a novel type of filler-vent, which is designed to thoroughly drain the emitted gas of all acid spray so that nothing but clean, dry gas is given off. The cell posts are molded into the body of the hard-rubber cover, making a perfect liquid-tight joint and the covers are effectively sealed into the container with special sealing compound. The thoroughly tight sealing and the spray-proof vents were designed primarily with a view to making a battery that could be used inside of a radio receiving set without subjecting the corrodible metal or other parts of the set to danger of injury from acid spray. The efficacy of the vent construction can be tested by anyone interested by placing litmus paper or copper gauze over the tops of the vents during a gassing charge of the battery at normal charging rates. Repeated tests of this character together

with the use of such batteries in close proximity to the inside works of radio receivers over a period of two years have completely demonstrated the soundness of the design. The upper part of the vent is shaped like a funnel and the internal design is such that water may be added to the cells by pouring it into the funnel-shaped part without removing or loosening the vent. This has the advantage of eliminating the danger of acid dropping from a removed vent cap; and adding water through the vent cap also washes back any acid that may have tended to creep out of the vent openings.

The charge indicator, visible through the glass at the end of the battery, removes the guess work from battery charging and eliminates the sloppy hydrometer. The indicator consists of two wax balls of different densities mounted in a hard-rubber cage which limits the movement of the balls to a pre-determined visible range. The cage is designed to allow free circulation of acid about the balls and at the same time to protect them from becoming coated with particles of active material from the plates. The balls are placed one above the other in the cage, the ball of greater density, of course, being placed below the other. The balls are made different in color for identification in assembly. The heavier ball is white and has a specific gravity of 1.265, while the lighter ball is colored and has a specific gravity of 1.200. At full charge, the normal specific gravity of the battery electrolyte is 1.285, which, of course, will float both balls to the top of the cage. As the battery is discharged, the specific gravity of the electrolyte decreases, as is well known, and if the battery is discharged completely at a low rate, the electrolyte specific gravity will fall to approximately 1.160. During the discharge each ball will drop to the bottom of the cage as the electrolyte specific gravity falls below its specific gravity. The balls will drop at approximately 20 per cent. discharge and 75 per cent. discharge, based on the useful capacity of the battery under average conditions of radio service. As the electrolyte specific gravity rises again during the recharge, the balls will rise one after the other and it will be known to the user that the battery is nearly up to the state of full charge when the second ball rises. For a complete charge the battery is kept on charge for about six hours at the normal charging rate after such time.

In order to protect storage batteries against self-discharge and deterioration during shipment and storage, some manufacturers have developed what are known as "drynamic" or dry-charged batteries and are producing and shipping both "A" and

"B" batteries this way. The plates of these batteries are formed, charged and dried before assembly. The dry-charged plates are assembled with a special form of dry porous separator and made into complete batteries. Since the cells contain no free acid or moisture and are sealed, they may be kept indefinitely without deterioration or loss of charge. When the dealer sells a battery he simply fills the cells with the proper electrolyte. The battery is then immediately ready for use without charging and will deliver from 60 to 80 per cent. of its rated capacity on the first discharge. The battery works up to full capacity with subsequent recharging and use. By this method of shipment, the dealer is saved the expense and time involved in charging batteries before delivery and the user is sure of getting a fresh battery that has not deteriorated on the shelf.

Since radio came in, the old and well-known scheme of making dry or non-spillable storage batteries has been revived and a number of both "A" and "B" batteries have come on the market with jelly electrolytes or with liquid electrolyte held in some form of absorbent filler. The chief objection to all such batteries is that the volume of active electrolyte is greatly reduced so that the battery capacity is also reduced. The free circulation and diffusion of the electrolyte is interfered with and resistance is interposed which causes increased heating of the battery during charge. Such a battery usually requires water more often, due to the reduced volume of free liquid and the increased heating. If the battery is allowed to run too long without adding water, the jelly or paste electrolyte may dry out to such an extent as to shrink and lose contact with the plates. When this happens the battery may be permanently injured by continued use. Jelly electrolytes are apt to cause abnormal softening and expansion of the plate active materials, very often resulting in early failure of the battery. These facts are well known to experienced battery manufacturers.

The storage battery suffers from an unreasonable prejudice against its use in some cases. Some people, usually not engineers, are almost superstitious about it and seem to consider complete battery elimination a goal to be reached at any cost. The storage battery probably inherits this prejudice by reason of the sloppiness and unsuitability for home use of early types. Also, until recently it has been necessary to give thought and go to some trouble to charge a storage battery, and few people like to mix thinking and trouble with their pleasures. These objections are completely met and the prejudice should be overcome by the use

for filament current of a small spray-proof battery of the improved design shown in Figure 2, combined with a small charger which is arranged to charge the battery automatically at a low rate during the time the radio set is out of use. Such a power unit is shown in Figure 3.

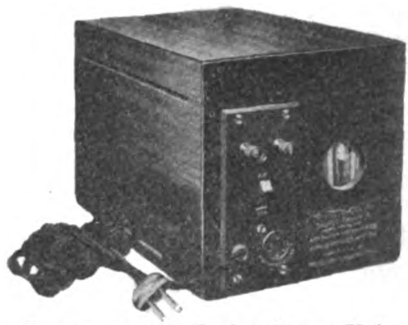

FIGURE 3—"A" Socket Power Unit

The battery supplies filament current just as does any "A" battery during the operation of the set when the switch that has been developed especially for the purpose is thrown on to ON. With this switch in the ON position, the trickle charger within the unit is disconnected and alternating current is switched on to the receptacle shown at the bottom of the panel in Figure 3, thereby energizing a separate "B" power unit designed to be plugged into the socket when it is desired to use such a device in conjunction with the "A" unit.

When the switch on the "A" power unit is thrown to OFF, the battery current is switched off the filaments, the alternating current is disconnected from the socket which feeds the "B" power unit and is connected to the trickle charger which delivers direct current to the battery. The operation of the radio set is controlled by this switch altogether, the filament rheostats and switch of the set being left in operating position.

The trickle charge rate may be adjusted to the conditions of use by means of three terminal taps marked "Low," "Med." and "High" at the top of the charger. These taps and other internal details are shown in Figure 4. The charge indicator, visible through the round opening alongside the panel (Figure 3), shows whether the proper setting is being used. If the two balls of the indicator are found to be at the top of the opening at the beginning of the day's use of the radio set, the battery is being kept charged. If one ball is up and one down, or if both balls are

down at the beginning of the radio day, the battery is not being kept up as it should be. Then, even though there is no noticeable difference in the operation of the set, the next higher tap setting should be used. The charging rate corresponding to each tap

FIGURE 4—Inside View of "A" Socket Power Unit

setting are approximately: 0.2 ampere for "low," 0.33 ampere for "medium" and 0.6 ampere for the "high" setting. The following table shows the average hours per day sets having different numbers of No. 201-A tubes may be operated on each tap keeping the battery charged:

Filament Current, Amperes	Equivalent Number of No. 201-A Tubes	LOW Tap 0.2 Amp.	MED. Tap 0.33 Amp.	HIGH Tap 0.6 Amp.
.25	1 No. 201-A	10.0	13.1	16.4
.50	2 No. 201-A	6.35	9.00	12.4
.75	3 No. 201-A	4.65	6.86	10.0
1.00	4 No. 201-A	3.66	5.54	8.40
1.25	5 No. 201-A	3.02	4.64	7.24
1.50	6 No. 201-A	2.57	4.00	6.35
1.75	7 No. 201-A	2.24	3.50	5.56
2.00	8 No. 201-A	2.00	3.13	5.10

It is obvious that a power unit of this type must be kept connected to the house socket at all times, except when the radio set is to remain out of use for a week or more, in which case it is advisable to pull the attachment plug from the house socket. The trickle charging rates are so low that the battery will not be harmed by continued overcharging for days or weeks at a time without being used, but it is best to avoid such extended overcharging in order to save current and not to use up unnecessarily the water in the battery. Ordinarily the battery, due to the special design and the low-rate charging, will need water only once in three or four months. Water is then added to each of the

three cells through the funnel-shaped vent cap to bring the level to the upper or high level line molded in the glass case.

Figure 5 shows the voltage characteristic of a 30-ampere-hour battery trickle charged at 0.33 ampere, 20 hours per day and discharged at 1.5 ampere, 4 hours per day, compared with a 120-ampere-hour battery discharged at 1.5 ampere, 4 hours per day following a full charge. The trickle-charged battery has a voltage peak lasting about five minutes at the beginning of each discharge period. During the remainder of the 4 hours, the voltage is very steady, dropping less than 2 per cent. The maximum voltage variation is from 6.6 to approximately 6.0 volts, a variation so small as to make filament rheostats unnecessary.

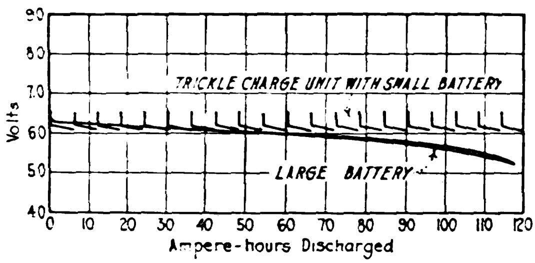

FIGURE 5

It will readily be seen that this type of "A" power unit is applicable to all existing sets using 5-volt tubes with the filaments in parallel. No adaptation or compromise of the circuit is necessary and the radio manufacturer may sell exactly the same set for operation with batteries and from the light socket. Since the alternating current is entirely disconnected from the battery and charger during the periods of use of the radio receiver, all possible complications by which the alternating current or the charger might cause a hum to be heard are avoided. By trickle charging at low current rates during the off periods, the size of the charger is kept to a minimum and the battery is charged in the best possible manner without gassing or heating.

"A" power units have been proposed in which the charger provides sufficient current to light the filaments and some extra current to keep the battery charged, the method of operation being that the charger is switched on only during the time the radio set is in use and both charger and battery are disconnected from the line during the periods of non-use. By this method the battery floats in shunt with the charger and load, where it acts as a smoothing device to keep down the peaks and fill up the valleys of

the pulsating rectified current. With this system there must be some method of regulating the charging rate so that it is always a little higher than the current taken by the filaments and the charger must necessarily be comparatively large. Even if such a system would furnish current of a character to give hum-free reproduction of good quality, which it usually will not do, the use of the system is likely to subject the tube filaments to a higher voltage than is good for them, owing to the fact that the charging current passing through the battery will cause the voltage to rise. Figure 6 shows this graphically in the case of a 6-volt, 30-ampere-hour battery connected to a filament load of 1.5 amperes and to a charger delivering 1.8 amperes. The periods of use were 4 hours per day, and it will be noted that the voltage is quite variable throughout the greater part of each period, rising from 6.4 to 7.0 volts.

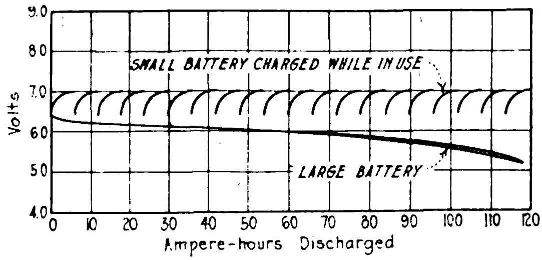

FIGURE 6

With the coming of the high-efficiency tubes, WD-11 and UV-199, the dry primary battery, which hitherto had figured as a source of "B" and "C" current only, entered into extensive use as an "A" source. The fact that this battery is non-spillable and can be placed inside of a set in any position are advantages which go a long way toward offsetting the relatively high cost of frequent replacements. It has not proven practicable to make dry cells larger than the common 6-inch size, and while this cell has proven quite satisfactory for sets having only a few tubes, it has decided limitations as a source of filament current for sets having six or more tubes. The 6-inch cell does not deliver satisfactory voltage and capacity if discharged at a rate higher than 0.25 ampere per cell, and preferably the rate should be kept below 0.2 ampere per cell. Where the filament current runs higher than this, it is necessary to add paralleled groups of cells.

One of the advantages of dry cells that has been much talked of is the convenience of replacement as compared with storage

battery recharging. This advantage disappears and the convenience, in the writer's opinion, must be conceded to the storage battery when the filament requirements are such that 9 to 12 six-inch dry cells grouped in series-parallel must be used, necessitating the loosening and remaking of 18 to 24 terminal connections each time the cells are replaced.

One of the serious problems in connection with dry-cell batteries seems to be that of getting fresh cells or batteries to the user. Slow self-discharge commences to take place in a dry cell as soon as it is made, and much of the dissatisfaction with dry-battery operation is, no doubt, due to the use of cells which have deteriorated while standing in stock.

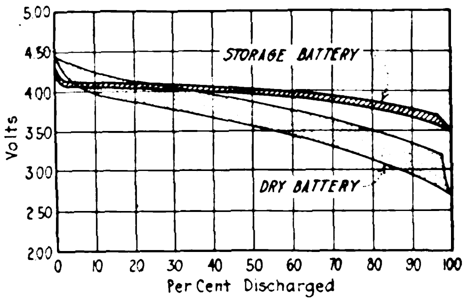

FIGURE 7

Figure 7 shows the voltage characteristics of three fresh 6-inch radio-type dry cells of a representative kind in comparison with a 15-ampere-hour, 2-cell storage battery which occupies somewhat less space than the three dry cells. This little storage battery is shown in Figure 8. The storage and dry batteries were discharged in series at 0.2 ampere, 4 hours per day, and voltage readings were taken at the beginning, middle and end of each discharge period. The curves are drawn so that the vertical width represents the variation in voltage from the beginning to the end of the daily 4-hour discharge periods while the slope of the curve shows the gradual falling off of voltage during the complete discharge cycle.

For more than 0.2 ampere of current, additional groups of dry cells should be connected in parallel to keep the discharge rate per cell below this figure. Even when this is done, the voltage variation during a daily discharge period and from the beginning to the end of the discharge cycle ia so great as to necessitate the re-setting of filament rheostats. The small storage battery, on the other hand, has good voltage characteristics at discharge

rates as high as 0.75 ampere and a single battery will satisfactorily operate sets having 8 or 10 No. 199 tubes. The storage battery, however, would have to be recharged more often than the dry cells would have to be replaced, since its ampere-hour capacity is less than that of a single group of three dry cells.

FIGURE 8 — Four-Volt Storage Battery with Built-in Charge Indicator

The charging, however, is taken care of automatically when such a battery is combined with a suitable trickle charger and switch, as is done in the combination "A" and "B" power unit shown in Figure 9.

This unit supplies pure battery current at 4 volts for receiving sets having 3-volt tubes, and when the tubes are turned off

FIGURE 9—Combination "A" and "B" Socket Power Unit for 3-Volt Tubes

by means of the special switch on the power unit, the battery automatically replenishes itself through an electrolytic trickle charger. Three taps inside the housing, marked "Low," "Med." and "High," permit of adjusting the trickle charge rate to the conditions of use, hand the carge indicator in the battery, visible

through an opening in the front of the housing, shows at a glance whether or not the battery is being kept charged.

The following table shows the average hours per day sets having different numbers of No. 199 tubes may be operated on each tap keeping the battery charged:

Filament Current, Amperes	Equivalent Number of No. 199 Tubes	LOW Tap 75 M.A.	MED. Tap 125 M.A.	HIGH Tap 200 M.A.
0.06	1 No. 199	12.6	15.6	18.0
0.12	2 No. 199	8.60	11.6	14.4
0.18	3 No. 199	6.52	9.20	12.0
0.24	4 No. 199	5.23	7.64	10.3
0.30	5 No. 199	4.38	6.53	9.00
0.36	6 No. 199	3.76	5.70	8.00
0.42	7 No. 199	3.30	5.04	7.20
0.48	8 No. 199	2.94	4.54	6.55
0.54	9 No. 199	2.65	4.12	6.00
0.60	10 No. 199	2.40	3.77	5.54

Special chargers of both the Tungar bulb type and electrolytic type have been developed and applied very successfully to trickle charging purposes. The bulb type has the advantages of compactness and being without liquid while the electrolytic type has better efficiency and longer life at the low current rates usually used. Figure 10 shows the alternating current input in watts at different charging rates for bulb and electrolytic type trickle chargers designed for use with 6-volt batteries.

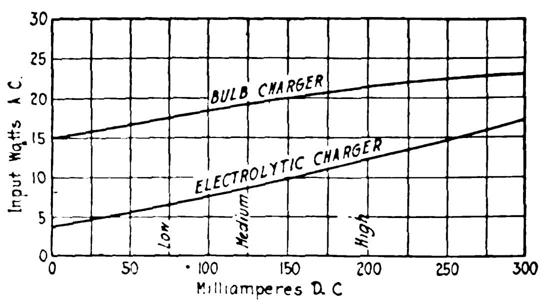

FIGURE 10

The difference in current consumption in favor of the electrolytic type is often sufficient to pay the cost of all rectifier cell renewals. The excess current consumed by the bulb type charger is accounted for principally as cathode-heating current. It will be seen that the two curves converge toward each other as the charging rate increases and at the higher current rates the bulb type charger would seem to have the advantage especially as the electrolytic type becomes bulky and requires the addition of water rather frequently at current rates above 0.75 ampere.

Figure 11 shows a similar comparison of the input watts for bulb type and electrolytic trickle chargers designed for use with small 4-volt batteries. At the very low trickle charge rates applying to receiving sets having the so-called dry-cell tubes, the electrolytic rectifier seems to have the advantages very much in its favor as regards both efficiency and life.

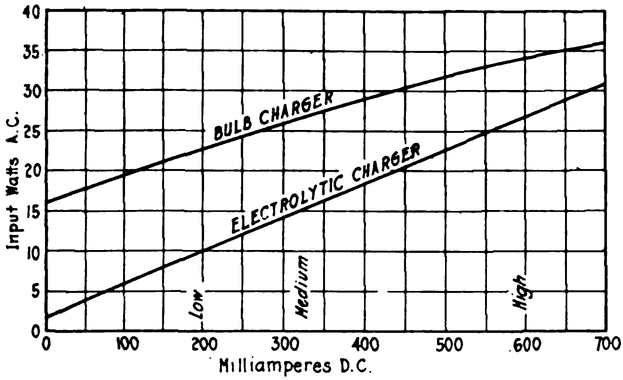

FIGURE 11

Among the methods proposed for heating filaments without the use of a battery may be mentioned the direct use of alternating current in the filament with a voltage-dividing connection and the use of a special type of tube having a cathode which is heated indirectly by conduction or radiation from a separate heating element carrying the alternating current. Neither of these devices has reached the practical stage as yet. There is little doubt that a tube using alternating current for indirect heating of the cathode will be developed and made practical before long, but there is good reason for thinking the performance of such tubes will not fully equal that of present types. Even if such tubes do come in and can be made to sell at a reasonable price, there will still remain a large field for battery-operated tubes in the homes which are not supplied with electric current.

With special circuits in which, as a rule, the tube filaments are all connected in series, some receiving sets are now being operated more or less successfully from alternating current by means of rectifiers and smoothing filters. With the small current required by No. 199 tubes in series, the problem is fairly simple, but for larger currents, even for that required by No. 201-A tubes with the filaments in series, there are numerous difficulties which have seemed almost insurmountable. How-

ever, the comparatively recent development of a reliable, long-lived electrolytic rectifier, capable of efficiently delivering the relatively large currents required, has altered the situation and opens up new possibilities. Figure 12 shows several sizes of the rectifier cells referred to.

These rectifier cells employ aluminum as the film-forming or rectifying electrode, but it is only in this respect that they re-

FIGURE 12—Philcotron Electrolytic Rectifice Cells

semble the unreliable aluminum-lead rectifier cells which have been a laboratory curiosity for many years. No lead is used in these cells. An anode of a special corrosion-resisting alloy is used instead with much benefit. The greatest improvement, however, results from the use of a new electrolyte solution. Even the aluminum electrode has been improved both chemically and physically. The result is a thoroughly-dependable, efficient and long-lived rectifier cell having exceptionally good characteristics for radio work. Its only disadvantage of any consequence is that it contains liquid. Chemically, however, this liquid is very mild and much less likely to cause damage than many other liquids used in the household. Ink, for example, has much greater potentialities for harm. Not a single case of damage by the solution has been reported during the more than two years that this electrolytic rectifier has been used extensively in radio battery chargers. The good electrical characteristics, the dependability and the inexpensiveness of this rectifier far outweigh the more or less sentimental objection that it contains liquid.

"B" Power Sources

The dry "B" battery was originally the only source of plate current. With the increasing use of multi-tube receiving sets demanding heavier plate currents, dry "B" batteries have steadily been increased in capacity and size. Some of the original small "B" battery units would not be considered large enough for use as "C" batteries today. With increased volume of pro-

duction, the dry-battery manufacturers have been able to reduce prices until the largest size 30-cell unit of today may be purchased for less than the price of a comparatively small unit formerly. This saving, however, has been offset by the growing tendency to use three instead of two "B" battery units as standard, and the dry "B" battery remains a relatively expensive, although very convenient, source of current.

Besides being convenient, dry "B" batteries have the advanatge of being clean, non-spillable, and capable of being used in any position.

The problem of getting fresh batteries to the user is even more troublesome with dry "B" batteries than with dry "A" cells, since the self-discharge in small cells goes on at a greater rate in proportion to their capacity. One of the chief reasons for the development of larger "B" batteries has been to provide a margin of capacity to partially offset shelf-deterioration.

The internal resistance of any battery increases as the discharge progresses. The internal resistance of dry batteries is comparatively high, even in fresh batteries, due to the nature of the materials used and to the large number of cells that must be connected in series for the required plate voltages. The internal resistance increases as the discharge progresses and the high resistance of old batteries seems to be responsible for certain imperfections in the radio reproduction with some types of receiving set. Certain frying or crackling noises have also been attributed to corroded or loose connections within dry "B" batteries. It is the writer's opinion that the amount of trouble from this cause has been greatly overestimated and that most of the noises for which dry batteries have been blamed has been merely static or local electrical interference of some sort.

As in the case of dry "A" batteries, the voltage of dry "B" batteries is quite variable both from the beginning to the end of a daily period of use and from the beginning to the end of the useful life of the battery. This is especially true when the plate current required by the set is above the average. Figure 13 shows graphically the voltage characteristics of a representative large so-called 45-volt dry "B" battery in comparison with 20-cell and 24-cell units of storage "B" battery when discharged at 25 milliamperes, 4 hours per day. This test schedule is undoubtedly in excess of average service requirements. However, it represents a requirement which has to be met in thousands of homes in every city and is well below maximum requirements both as to current rate and time.

The vertical width of each curve represents the dropping of voltage during the daily 4-hour discharge periods, while the slope of each curve shows the falling off of voltage during the discharge cycle or useful life. It will be noted that the dry battery falls away from the nominal 45-volts quite early, showing the fallacy of rating this battery in terms of its initial voltage. The storage battery gives fairly constant voltage during the greater part of the discharge. It will be seen that the 20-cell storage battery unit which nominally, as storage batteries are rated, is a 40-volt battery, actually has somewhat higher average voltage than the so-called 45-volt dry battery unit. Most radio engineers are aware of this discrepancy between the nominal and actual volt-

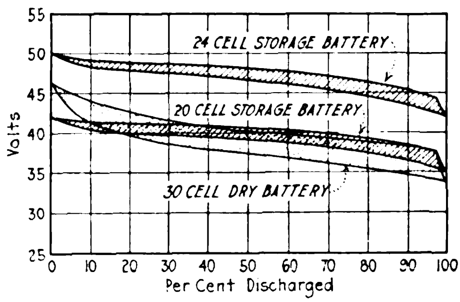

FIGURE 13

age of the dry battery and are designing sets for operation at average dry battery voltages rather than at the initial or nominal voltages. It is not surprising, therefore, that a storage "B" battery, made up of 20-cell units, often gives better results than the higher voltage storage battery made up of 24-cell units which has been commonly used heretofore.

Storage "B" batteries give excellent results, due to their good voltage characteristics and low internal resistance, but they are considered objectionable by persons who do not understand their charging and care. Early types also were sloppy, bulky and inconvenient to charge and use. These objections have been largely overcome by improved battery design and the development of convenient chargers. Figure 14 shows a 40-cell storage battery unit made up of square cells of 3,000 milliampere-hours capacity. A similar unit is made with cells of 6,000 milliampere-hours capacity having the same overall width and length but greater height.

The use of the square jars with square sealed covers in the place of round jars with threaded tops and screw covers elimin-

ates waste space both between and within the cells, making the battery more compact. Sufficient acid space is provided above the tops of the plates so that the cells may be used a full year under usual conditions without adding water and the design is such that water may be added conveniently by pouring it in a depression in the cover. Charge indicators similar to those used in the small glass-container types of "A" battery are built into certain front cells so that the state of charge or discharge of the battery is indicated visibly. The battery unit is provided with Fahnestock terminals conveniently located at the front.

Among the many "B" battery substitutes or eliminators that have come on the market during the past year a few stand out

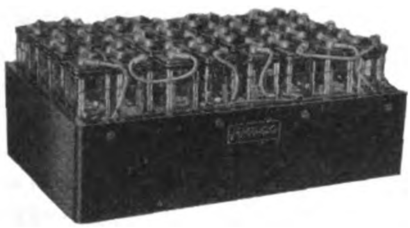

FIGURE 14—40-Cell Unit of Storage "B" Battery

as being successful. These power units all operate on the same general principle and consist essentially of a transformer, a rectifier and a smoothing filter. The chief differences among different units are in the kind of rectifier and the details and size of the smoothing filter. The electrical principles upon which these battery substitutes are based are well known to radio engineers and will not be discussed at length in this paper.

It seems to be important to use a type of rectifier which will pass uniformly-undulating current with a minimum of irregularities or harmonics, and the gas-filled, hot-cathode bulb which is so commonly used in battery chargers does not seem to be well adapted to this purpose. Two general types of rectifier, namely, the vacuum tube and the electrolytic types, have proven most successful. The tube rectifiers used are either of the true thermionic valve type or of the cold-cathode gas-filled type.

Tube rectifiers have the advantage of being compact, dry and clean. They have had the disadvantage in the past of short life, but undoubtedly the life of the new types recently placed on the market will prove satisfactory. The most serious disadvantage of tube rectifiers, whether of the heated or unheated-cathode

type, is their high internal resistance or impedance which necessitates the use of a high-voltage transformer. The current consumption is, therefore, relatively high, and usually at least 80 per cent. of it goes to generate heat in the rectifier tube itself. Due to this high impedance characteristic, the voltage of the rectified current will vary greatly with changes in the load current unless some special regulation is provided such as a potentiometer resistance or a regulator tube. Such regulators, of course, increase the current consumption of the device and add to the already-high heat losses, necessitating adequate ventilation.

Two types of electrolytic rectifier are used in "B" power units, one using tantalum as the film-forming or rectifying electrode, the other using aluminum. The electrolyte is sulphuric acid in the tantalum rectifier and a solution containing several substances, chiefly salts, in the aluminum rectifier. The tantalum rectifier in its present stage of development will stand only a very limited voltage per cell and in a 90-volt "B" battery substitute it has been found necessary to use not less than six cells in series for half-wave rectification. The aluminum rectifier will stand at least three times as much voltage per cell as the tantalum rectifier, so that only two cells need be used in series for half-wave rectification under the same conditions. However, there is always some danger that cells in series, connected for half-wave rectification, will not start rectifying at the same moment after a period of idleness, so that the one cell may take the full voltage which should be divided up equally among the cells in the series. When this occurs, the one cell which is taking practically all the load may overheat and break down, thus throwing an excessive load on the remaining cell or cells with probable injury to them also.

A single aluminum rectifier cell may be used for half-wave rectification to charge "A" batteries or 24-cell "B" batteries from a 115-volt secondary or line. In this case, the battery voltage is in series with the supply voltage on the suppressed half-wave which tends to break down the rectifying film so that the film has to withstand a voltage peak of 115 times 1.41 plus 60 volts, or approximately 220 volts. However, when used in combination with the usual smoothing filter, a single aluminum cell should not be used on an alternating current supply voltage higher than 75 volts. The reason for this is that the condensers of the filter circuit charge up to a voltage approaching the peak voltage of the alternating current supply and on the suppressed

half-wave this condenser voltage is in series with the transformer or supply voltage. In this case, the voltage tending to break down the rectifying film would approach 75 times 1.41 times 2, or about 230 volts.

For direct-current potentials up to 135 volts in "B" power units, it has been found desirable and practicable to use four aluminum cells connected in a so-called bridge circuit for full-wave rectification, using a transformer designed to give a secondary voltage of 150 r.m.s. volts on open circuit. This transformer voltage must not be exceeded. The perfected aluminum cells referred to in this paper will operate satisfactorily and dependably under such conditions. The loss of voltage in the rectifier cells themselves is so small that 135 volts may easily be obtained at usual loads provided the choke coils used in the smoothing circuit have not more than 700 ohms resistance.

Aluminum rectifier cells should never be used with a center-tap transformer connected for full-wave rectification in the manner that is common with tube rectifiers. Even with tube rectifiers there is a possibility of trouble from unbalancing of the load in such a circuit and there are also good possibilities of burning out the transformer in case of short-circuit in one of the rectifiers.

Figure 15 shows a hook-up that is being used very successfully to supply both "A" and "B" power from the lamp socket under

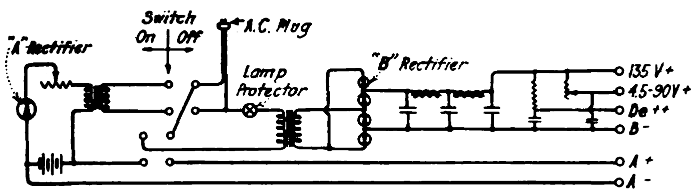

FIGURE 15

the control of one switch. The bridge hook-up of four aluminum rectifier cells referred to above is shown in this diagram. The entire "A" and "B" supply may be built into a radio receiver or a combination power unit such as that shown in Figure 9, or the "A" and "B" parts may be built into separate units designed to be used either separately or in combination. Figure 16 shows a separate "B" power unit embodying the full-wave rectifying system and filter circuit shown diagrammatically in Figure 15. The four small aluminum rectifier cells used in this unit are designed to snap into special sockets in just one way so that wrong connections cannot be made. One set of four costing

no more than a full-wave rectifier tube will operate at least 2,000 hours in average "B" service without any attention whatever. They are so designed that water need never be added. Replacement cells as well as the original cells are shipped filled and corked, ready for immediate use when the corks have been removed and the cells snapped in place of the old ones. There are no delicate parts in these rectifiers and no particular accuracy

FIGURE 16—"B" Socket Power Unit

of manufacture is required, so that there is very little chance of defectives.

The lamp protector used in the primary circuit of the transformer which feeds the "B" rectifier cells, as shown in Figure 15, is an important element of this "B" power unit. This protector consists of a standard 115-volt Mazda lamp and its prime function is to protect the rectifier cells and transformer against overload in starting up after a period of idleness as well as when the rectifier cells ultimately break down and pass alternating current. The lamp also serves as a protection in case of short-circuit anywhere in the "B" unit and limits the current obtained at the terminals on short circuit to a value which will not burn out tube filaments if connected to the "A" terminals of the set. The short-circuit current is great enough to burn out one No. 199 tube or even two connected in parallel; but the owner of a set having not more than two such tubes surely would not be using a "B" power unit. Standard tungsten lamps have been found most suitable for the protector on account of their very high resistance-temperature coefficient and also because they offer a convenient means of adjusting the direct current output voltages when required for receiving sets which draw an exceptionally small or exceptionally large plate current. Usually a 40-watt or 50-watt regular Mazda lamp is shipped with the outfit. By changing to

a smaller or larger lamp, the voltage applied to the transformer primary is lowered or raised with a corresponding effect on the output voltage. Normally, the filament of the protective lamp is only heated enough to be just visible and the voltage drop therein amounts to only a few volts. In starting up after a period of idleness, however, the lamp burns brightly and the voltage drop in it is high, so that only a low voltage reaches the transformer primary during the few seconds that is required for the film to re-form on the rectifying electrodes. By this means, the initial current which passes through the rectifier cells and the starting load on the transformer are very greatly reduced. The same thing occurs and the same protection is afforded ultimately when the rectifier cells become worn out. The continued bright burning of the lamp at any time is a signal of non-rectification, wrong connections or trouble.

Figure 17 shows the voltage characteristics at the "135-Volt +" post using different lamps in the socket in the primary cir-

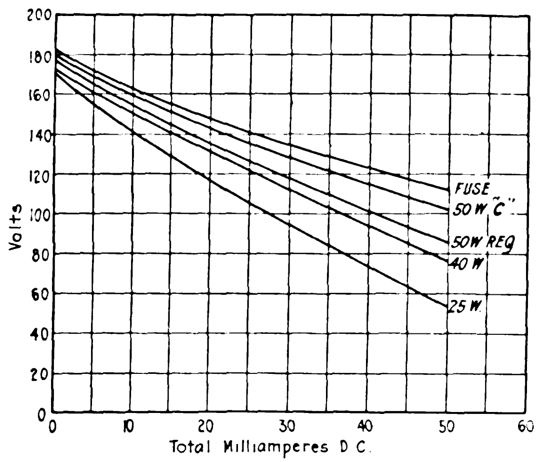

FIGURE 17

cuit. The highest curve was made with a fuse in the socket for the purpose of showing the voltage characteristic with no resistance in the primary circuit. But the regular use of the power unit with a fuse in the socket cannot be recommended; in fact, the 50-watt Mazda "C" or gas-filled lamp is the largest that should be used under any circumstances. Where a change of the lamp shipped with the outfit is required, it is usually to a smaller rather than to a larger size.

Referring again to Figure 15, it will be noted that a fixed

resistor is used to bring down the high voltage to detector voltage while a variable resistor is used to provide 45 to 90 volts or more at a second amplifier post, which will be referred to as the "B Amp.+" post.

Figure 18 shows the variation in voltage obtainable with different loads up to 50 milliamperes at the "B" Amp.+" post with

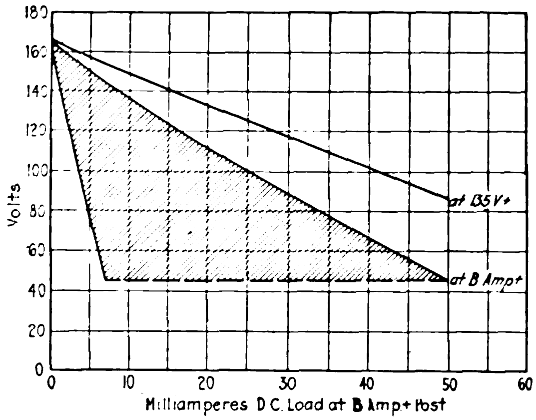

FIGURE 18

a constant load of 6 milliamperes in addition at the "135-Volt+" post. These curves were made with a 50-watt regular Mazda lamp in the primary socket. Any voltage within the shaded area may be obtained, over the large current range shown, by adjustment of the variable resistor which is connected between the "135-Volt+" post and "B Amp.+" post.

In a unit designed to operate with "hard" detector tubes, the detector voltage may be regulated by means of a fixed resistor to a value of 25 to 35 volts. This has been found by practical tests of many radio sets to be the best compromise detector voltage although with most sets using "hard" detectors the voltage may come anywhere between 20 and 40 volts without affecting the results appreciably. With "soft" or gas-filled detector tubes the case is different, and if it is desired to make a "B" battery substitute that will satisfactorily operate sets using "soft" detectors, it is necessary to provide means for adjusting the detector voltage closely to a particular value somewhere between 15 and 20 volts.

Figure 19 shows characteristic curves of a full-wave electrolytic "B" power unit designed to give 90 volts at a load of 40 milliamperes or less in comparison with representative "B"

power units using full-wave and half-wave tube rectifiers. The filament adjustment provided in the half-wave tube unit was set to give the normal 5 volts at the filament during the test run. No filament adjustment was provided on the full-wave tube outfit. The very high output voltages of tube-type outfits at low current rates often paralyze the radio tubes so that no sound is

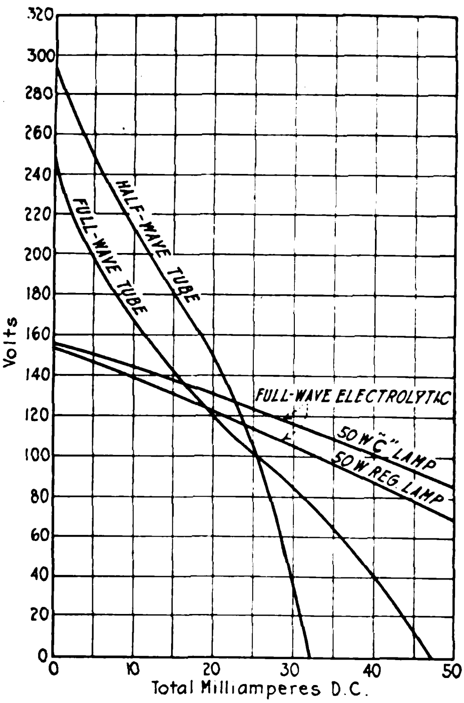

FIGURE 19

heard and the user thinks that the outfit is not operating. Such high-plate voltages, of course, are very damaging to radio tubes having thoriated or coated filaments. The voltage can be reduced to a certain extent by filament adjustment when hot-cathode rectifying tubes are used, but it is rather too much to expect of the average user that he will know by the quality of the reproduction whether or not he is using a plate voltage that will seriously endanger his radio tubes. With the electrolytic power unit the maximum open-circuit voltage is only about half that of the average tube-type unit and the voltage at low current rates can readily be brought down to any predetermined fixed value by the use of a small lamp in place of a 50-watt lamp in the primary circuit.

The relatively high transformer voltages that must be used with high-impedance rectifiers, such as thermionic and cold-cathode tubes, subjects the condensers of the filter circuit to a severe strain, and it has been a problem to make condensers at a reasonable cost that would stand up in such service. The use of low-impedance electrolytic rectifiers with the comparatively low-voltage transformers thereby made possible solves the condenser problem by removing the excessive strain.

Figure 20 shows the alternating-current watts input in relation to the direct-current load for electrolytic and tube-type

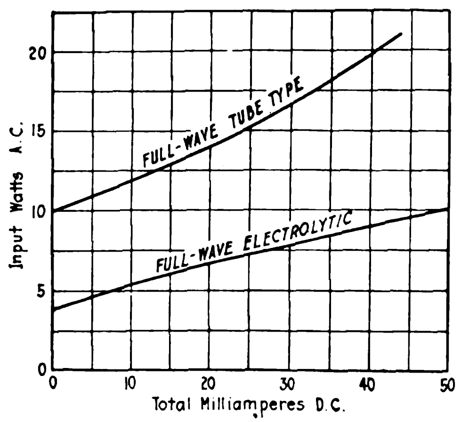

FIGURE 20

"B" power units of the full-wave type. The greater current consumption of the tube-type unit is accounted for by the filament-heating current and the losses due to the high plate-filament impedance of the tube. With regulator or ballast tubes added, the current consumption of the tube-type unit would be considerably greater than is shown in the curve.

"C" VOLTAGE SOURCES

There is some demand for the elimination of "C" batteries, especially where the new UX-120 tube is used in the last audio stage requiring 22½ volts grid bias. The necessary negative voltage can be incorporated in a battery substitute circuit and used successfully where the receiving circuit is adapted to it. It is a question, however, whether battery biasing is not simpler and better.

The writer's experience with dry "C" batteries has been that at least one year's life can be expected of even the smallest of

them and that they are no trouble to replace. Certainly there is no need for a storage battery in this service and little need for the complications involved in "C" battery elimination.

It is unfortunate that the little but important "C" battery is sometimes mounted underneath the receiving set or stowed away in some inaccessible place. It is not strange that in such cases the user often fails to renew the "C" battery; that he in fact does not know there is such a thing until eventually he calls in a service man to find what is the matter with the set. It would seem to be good business to place the "C" battery in plain sight inside the set with a special instruction card close by it stating that it must be replaced once a year.

Concluding Remarks

Rectifiers and smoothing filters, which are the basis of all present battery substitutes, are very old devices and were used even in combination long before the days of radio. The old German patent to Koch and Sterzel, dated December 5, 1906, showed such a combination. The successful application of the idea to radio awaited only the development of a suitable rectifier.

There does not seem to be anything very complicated about the design and action of a smoothing filter, notwithstanding the mass of mathematics in the literature on the subject. The condensers appear to act simply as storage tanks which receive the impulses of rectified current and deliver current of smoother form. The choke coil appears to act as a fly-wheel, or perhaps we should say as a turbine having a fly-wheel, which tends to keep the current flowing smoothly in one direction. A double-section filter consisting of two choke coils and three main condensers seems to be more economical of material for a given result than a single-section filter consisting of one larger choke coil with two larger condensers. Good smoothing can be obtained either way. The important thing seems to be to have ample choke coil inductance and condenser capacity.

Naturally, the continuous succession of current ripples from a full-wave rectifier is easier to smooth out than the separate surges of current from a half-wave rectifier. Half-wave rectification necessitates a larger smoothing filter than full-wave rectification for satisfactory results as to hum elimination. Even when no real hum is produced, the use of a half-wave type power unit will often cause a low gurgling or fuzziness in speech or solo voice reproduction, apparently due to current undulations or irregularities at a frequency below the audible range. This form

of distortion may not be noticed by the average listener, but it is very objectionable to the critical ear.

Some radio receivers, notably radio-frequency loop sets having one or more reflexed stages, are difficult to operate without hum on an ordinary "B" battery substitute and require some special provision for grounding to eliminate the hum even when the best of smoothing filters is used. In other cases, the receiving set is very sensitive to magnetic induction by the transformer of the power unit, so that the power unit must be placed at a distance from the set, or very heavy shielding must be used. Close cooperation between the set manufacturer and the power unit manufacturer can be the means of eliminating these exceptional difficulties and should bring about a simpler and better use of the principles embodied in present socket power units.

SUMMARY: This paper describes and gives characteristics of the various present-day sources of "A," "B," and "C" power for radio receivers, namely, storage batteries, dry primary batteries, trickle-charge power units and battery substitute devices.

The development of radio storage batteries from the earliest types up to the highly-specialized radio "A" and "B" batteries of today having built-in charge indicators, visible water level and spray-proof construction is traced and information is given on "A" socket power units containing such batteries in combination with newly-developed trickle chargers.

Announcement is made of a perfected aluminum electrolytic rectifier. "B" battery substitutes embodying this rectifier are described and their electrical characteristics are given. Rectifiers and smoothing filters generally and their application to radio uses are discussed.

DIRECTION DETERMINATIONS OF ATMOSPHERIC DISTURBANCES ON THE ISTHMUS OF PANAMA*

By

L. W. Austin

Laboratory for Special Radio Transmission Research

Conducted Jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy.

It has long been known that atmospheric disturbances in general originate over land rather than over the ocean. It is also known that the sources of the tropical disturbances seem to follow the sun in its changing path between the northern and southern hemispheres.[1]

It was therefore to be expected that during the winter in Panama (10° north), the atmospheric disturbances would come chiefly from the mainland of South America, while in summer they might be expected to come from the direction of Central America and Mexico. In addition, during the rainy season, it could be assumed that there would be a considerable amount of local disturbance generated in the low mountain chain which forms the backbone of the isthmus. It was not known, however, whether these local disturbances would outweigh those coming from the larger land masses.

During February and March, 1925, I made directional observations on the atmospheric disturbances at frequencies of 21.4 and 15 kc. (14,000 and 20,000m.) in the U. S. Naval radio receiving stations at Balboa and Colon, at the two ends of the Panama Canal. The measurements were afterward continued by the personnel of the two stations.

The method used in the measurements was first described in 1920.[2]

[1]DeGroot, The Proceedings of The Institute of Radio Engineers, vol. 5, page 75; 1917. Goldschmidt and Braillard, La T. S. F. au Congo Belge, Hayez 112, Rue de Louvain Bruxelles, 1920. Austin, Journ. Franklin Institute, p. 619; 1921. Round, Eckersley, Tremellen & Lunnon, Journ. I. E. E. (London), vol. 63, page 62; 1925.

*Received by the Editor, April 11th, 1926. Published by permission of the Directors of the National Bureau of Standards of the Department of Commerce.

[2]Austin. Journ. Franklin Institute, page. 619; 1921.

The apparatus shown in the figure consisted of an 8-ft. (2.44-m) coil antenna with 48 turns, which was combined with a small single-wire antenna to form a unidirectional receiving combination. In the measurements the general direction was first found by rotating the coil and adjusting the antenna coupling and resistances until the disturbance maximum was obtained with the antenna reversing switch S thrown in one direction, and the minimum when it was thrown in the other. The absolute

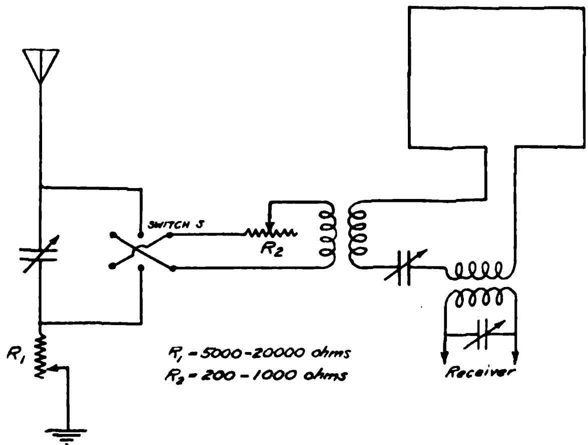

FIGURE 1

direction in which signals were strengthened with the switch in a certain position was determined by observations on a transmitting station in a known direction. When the general direction had been determined, the coil was turned approximately at right angles to the indicated disturbance direction; the switch S was then rapidly reversed, the coil being at the same time slowly moved until the position was found in which the sound of the disturbances in the telephones was of the same intensity with the switch in its two positions. In general there were a certain number of degrees on the coil scale over which the sound equality was maintained. The center of this zone of equality was the scale reading for which the coil was at right angles to the average disturbance direction, since in this position the coil was inactive, the whole reception being from the antenna. By this method good readings can be obtained when no direction at all can be observed on the coil antenna alone.

The Table shows the results of the observations from February to November, 1925. Those taken from February to

the end of June were made by observers who had received personal instruction in the method of measurement and are considered more reliable than those taken later. Owing to changes in the personnel of the stations, the work was apparently entirely interrupted during July and August. During the months in which accurate measurements were generally possible, the bearings in the table are given in degrees, During the more disturbed periods the directions are only roughly indicated.

DIRECTION OF ATMOSPHERIC DISTURBANCES AT BALBOA AND COLON
FEBRUARY TO NOVEMBER, 1925

	BALBOA			COLON		
		No. of Obser-vations			No. of Obser-vations	
	3 P.M.	10	All (120°-130°)	—	—	—
March	10 A.M.	—	— — —	10 A.M.	9	All (120°-130°)**
	3 P.M.	25	All (125°-135°)	3 P.M.	9	All (130°-140°)
	10 P.M.	—	— — —	10 P.M.	9	All (120°-140°)
April	10 A.M.	7	7 NB*,	10 A.M.	28	All (120°-145°)
	3 P.M.	29	20 NB, 7 SE, 1N, 1E	3 P.M.	25	All (130°-145°)
	10 P.M.	7	5 NB, 2N	10 P.M.	23	All (120°-140°)
May	10 A.M.	9	4 NB, 5 (NW-N)	10 A.M.	16	2 NB, 14 SE
	3 P.M.	31	15 NB, 15 (NW-N), 1 NE	3 P.M.	13	2 NB, 11 SE
	10 P.M.	9	8 NB, 1 NE	10 P.M.	3	3 SE
June	10 A.M.	9	3 NB, 6N	10 A.M.	15	All SE
	3 P.M.	30	5 NB, 25 N	3 P.M.	14	All SE
	10 P.M.	9	9 NB	10 P.M.	4	All SE
			No observations in July and August			
Sept.	—	—	— — —	10 A.M.	30	1 NB, 29 SE
	—	—	— — —	3 P.M.	30	1 NB, 28 SE, 1 S
	—	—	— — —	—	—	— — —
Oct.	10 A.M.	31	26 (NW-NE), 5 SE	10 A.M.	31	All (130°-140°)
	3 P.M.	31	3 NB, 23 (NW-NE), 5 SE	3 P.M.	31	All (130°-145°)
	10 P.M.	31	25 NB, 5 (W-N), 1 SE	—	—	— — —
Nov.	10 A.M.	30	19 (E-SE), 8 (NW-NE), 3 (S-W)	10 A.M.	30	All (135°-140°)
	3 P.M.	30	1 NB, 20 (SE-S), 3 (SW-W), 6 (NW-NE)	3 P.M.	30	All (130°-145°)
	10 P.M.	15	13 NB, 1 SE, 1 NE	—	—	— — —

* NB—No definite bearings.
** The angles are measured clockwise from north.

The data obtained seem to warrant the following conclusions:

1. During the dry season, probaly from January 15 to April 1, the atmospheric disturbances both at Balboa and Colon come almost entirely from the South American continent, from the direction of the high Andes in northern Colombia.

2. When the dry season comes to an end and local storms begin to appear, the local disturbances from the low mountains of the isthmus begin to be prominent. This shifts the prevailing

direction at Balboa at times from the southeast to the north, but has little effect on the direction at Colon since the mountains containing the local centers of disturbance here lie to the south and east, or roughly in the direction of the disturbance sources in Colombia.

3. In midsummer, while there is probably much disturbance from Central America and Mexico, the local disturbances from the isthmus mask this to such an extent that the prevailing direction at Colon continues roughly southeast, while at Balboa the distant and local disturbances unite to give a northerly or northwesterly direction.

4. The observations further indicate that from northern sending stations, Balboa and Colon should give nearly equally good unidirectional reception in the dry season, but during the rest of the year, where the disturbance conditions are more troublesome, Colon should have considerable advantage over Balboa.

PRELIMINARY NOTE ON PROPOSED CHANGES IN THE CONSTANTS OF THE AUSTIN-COHEN TRANSMISSION FORMULA*

By

L. W. Austin

(Laboratory for Special Radio Transmission Research)

(Conducted jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy)

It has been known for a number of years that the Austin-Cohen transmission formula, while satisfactory for moderate distances and wave lengths, gives values at 6,000 km. which are only about one-half of those observed, and that at 12,000 km. the ratio appears to be about one to four.

Our original formula for daylight signals over salt water of 1910-1914[1] was written

$$E = 120\,\pi \frac{h\,I}{\lambda\,d}\sqrt{\frac{\theta}{\sin\theta}}\,e^{-u} \text{ (volts km. amp.)}$$

where $u = \dfrac{0.0015\,d}{\lambda^{0.5}}$. The constants in u were determined empirically from shunted telephone observations for distances up to 2,000 km. and frequencies between 1,000 kc. ($\lambda = 300$ *m.*) and 80 kc. ($\lambda = 3{,}750$ m.).

Naturally I have been desirous of bringing the formula into better agreement with the observations. Acting on the advice of some of my European colleagues in the URSI, I have given up the idea of altering the Hertzian portion of the formula since this is the portion that rests on a theoretical basis, and have given attention only to possible changes in the values of the constants of the exponential term. These can easily be arranged so as to give excellent agreement for limited ranges of wave length and distance, but in order to give the formula a general character, it should be at least approximately accurate for all frequencies between $f = 1000$ kc. ($\lambda = 300$ m.) and 12 kc. ($\lambda = 25000$ m.)

*Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce. Received by the Editor, February 15, 1926.

[1] Bureau of Standards Bulletin VII, p. 315, 1911, Reprint 159; and XI, p. 69, 1914, Reprint 226.

During recent years a very considerable amount of experimental data on signal field strength has been collected. Long series of transatlantic observations have been taken by the American Telephone & Telegraph Company, The Radio Corporation of America, The Marconi Company, the French Army at Meudon, near Paris, and the Bureau of Standards. The Marconi Company has also collected a vast amount of experimental reception data from various transmitting stations during the voyages of the S. S. *Dorset* from England to New Zealand (February and March, 1922) by way of the Panama Canal, and of the S. S. *Boonah* from Australia to England (June, July, August, 1923) through the Suez Canal. In addition, the Indian Post Office made field intensity measurements at Karachi, India, on several of the European high-power stations from November, 1921, to January, 1923.

All this material now makes it possible to determine the variations of field intensity with varying wave length and distance with some degree of certainty. The relative value of the different series of observations of course differs widely. Those in which the same stations are observed regularly over one or more years are naturally the most valuable. Those which have been taken during the voyages of ships, while important, may show large variations during different parts of the voyage, since in general only one observation is taken at any given distance from the transmitting station, and the results can at best represent the conditions during only limited portions of the year.

The use of much of the experimental material for deriving a formula which must by definition hold for an all-water path is complicated by the fact that in most cases of long distance transmission the waves pass for a considerable distance over land. For example, the shortest great circle distance between Nauen, Germany, and Washington is roughly 25 per cent land, Rocky Point to London twenty per cent., Buenos Aires to Washington more than fifty per cent, while from Karachi, India, to the European transmitting stations nearly the whole path is over land.

The question of the relative land and water attenuation in radio transmission is not at all settled. It is generally agreed that for wave lengths below 5,000 m., land attenuation is much greater than that over water, and it seems probable that there is considerable, though decreasing, land effect from 5,000 m. up to at least 15,000 m. The amount of this effect naturally depends upon the character of the land traversed, and especially on conditions in the neighborhood of the transmitting and re-

ceiving stations. Observations at Washington covering more than two years indicate that signals from Bolinas, California, near San Francisco $f=22.9$ kc. ($\lambda=13{,}100$m.) have practically the same attenuation as over water, if the reported effective height of the station is correct. On the other hand, a much more limited number of observations in Washington on San Diego, and in San Diego on the east coast stations indicate nearly twice the water attenuation. This may be due to local conditions near San Diego as this has always been thought by operators to be less favorable for radio work than San Francisco.

Notwithstanding these uncertainties, it has seemed worth while to make use of the accumulated data for obtaining at least tentative constants for a new formula. Up to the present a value of $u=\frac{0.0014\,d}{\lambda^{0.6}}$ seems to give fairly satisfactory results. This may be slightly varied as more and better observational data are obtained. Table 1 gives the ratio of the new to the old values of e^{-u} at various wave lengths and distances, and Table 2 shows a collection of observed intensity values from various sources which are in good, or fairly good, agreement with those calculated according to the revised formula. The observations at Cliffwood and New Southgate[1] were taken by the American Telephone and Telegraph Company and those at Karachi by the Indian Post Office.[2]

TABLE I

RATIO OF NEW AND OLD VALUES e^{-u}

λ km.	d km. 500	1,000	2,000	4,000	6,000	12,000
0.3	0.93	0.86	0.72			
0.5	1.00	1.00	1.00			
1.0	1.05	1.11	1.22			
2.0	1.07	1.14	1.31			
3.0	1.07	1.15	1.33	1.77		
5.0			1.32	1.72	2.25	
10.0			1.31	1.62	2.09	4.40
16.0				1.55	1.94	3.75
24.0					1.80	3.25

The series at San Diego[3] was taken by the Bureau of Standards, while the Marion and Nauen observations on the S. S. *Dorset* and *Boonah*[4] by the Marconi Company represent the averages taken from the observation curves of the two ships, one in March, 1922, and the other in July, 1923. Bordeaux

[1] "Bell System Technical Journal," vol. 4, p. 459; 1925.
[2] "London Elec.," vol. 91, p. 164; 1923.
[3] "Jour. Wash. Acad. Sci.," vol. 15, p. 139; 1925.
[4] "Jour. I. E. E." (London), vol. 63, p. 933; 1925.

changed its wave length from 23,400 m. to 19,000 m., at about the time the *Boonah* sailed from Australia, and this change resulted in such an increase in the efficiency of the station that the observations on the two ships could not be fairly compared.

In a later paper the rest of the available data, both favorable and unfavorable to the formula, will be discussed.

TABLE II

Some Calculated and Observed Field Intensities

Sending Station	Receiving Station	f kc.	λ km.	d km.	E $\mu v/m$ cal.	obs.	
Nauen	Cliffwood, N. J.	23.8	12.6	6,350	44	42	1922-1923
Marion	New Southgate, Eng.	25.8	11.6	5,280	40	53	1923-1924
Rome	Karachi, India	28.0	10.7	5,230	24	20	Nov., 1921 to
Bordeaux	Karachi, India	12.8	23.4	5,900	60	68	Jan., 1923
Ste. Assise	Bureau of Stds.	20.6	14.5	6,150	53	48	1923
Bordeaux	Bureau of Stds.	12.8	23.4	6,160	67	71	1922
Buenos Aires	Bureau of Stds.	23.6	12.7	8,300	30	37	1924
Cavite, P. I.	San Diego, Cal.	19.3	15.5	11,800	2.7	2.0	Aug. 28-Sept. 22, 1924
Marion	S.S. Dorset & Boonah	25.8	11.6	8,000	11	12	March, 1922 and
				12,000	2.7	3	July, 1923
Nauen	S.S. Dorset & Boonah	23.8	12.6	8,000	21	22	March, 1922 and
				12,000	5.4	5.5	July, 1923
Bordeaux	S.S. Dorset	12.8	23.4	8,000	37	33	March, 1922
				12,000	13	10	

CHOICE OF POWER FOR A RADIO STATION*

By

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and

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The present development of the radio telegraphy is so advanced that the engineer who is designing a radio station has numerous alternative possibilities in solving his problem. He has available three methods of generating continuous waves, these three systems being by the arc, electron tube generator, or radio frequency alternator. The capabilities which these systems offer with respect to power and operating characteristics certainly solve the question of radio communication within the limits of terrestrial distances. There remains only the perfecting of details which do not affect fundamental methods.

The great increase in the available power of generators allows one to solve the problems of radio communication free from narrow technical limitations, as was the case for the earlier spark transmitters. For such spark sets, the constructor was often stopped by the limits of available power, voltage, speed of transmission, and the like, and for these reasons he had to sacrifice economic considerations to technical requirements.

At present the conditions are such that the quantitative design of a radio station can and, therefore, must be considered from an economic point of view, bearing in mind the expenses incurred in the installation and maintenance of the station.

N. Tsiklinsky showed analytically in 1922 that, for a given radio circuit, there is some satisfactory power for which the cost of the radio transmitter is a minimum.[1]

Messrs. E. F. W. Alexanderson, A. E. Reoch, and C. H. Taylor in a paper on trans-Atlantic radio transmission also suggested

*Presented before the Russian Society of Radio Engineers, Leningrad; in mathematical form by N.N. Tsiklinsky, June 22, 1922, and in final form by V. I. Volynkin, February 24, 1925. Received by the Editor of The Institute of Radio Engineers, July 25, 1925.

[1] "Telegrafia i telefonia bez provodov," number 15, 570-574, August, 1922.

that there is a minimum cost of a radio transmitter for a certain height of the masts and they published two curves of relative cost as a function of the height.[2]

In this paper, an attempt is made to approach this question chiefly from the point of defining that power of the radio station which will give the desired service with the smallest outlay for installation and maintenance.

The cost of a radio transmitter may be looked upon as made up of the combined value of buildings, generating equipment, the antenna with its masts, and the ground connection. Leaving out of consideration the cost of the building as not dependent on the power but determined by other considerations, let us consider the relation between the other three quantities. It is known that the same received signal can be realized by an increase of power of the transmitter and a corresponding reduction of the height of antenna and vice versa. With an increase of power there is an increase in the expenses for machinery and ground connection, but at the same time the cost of the antenna decreases. Combining these components of cost, we can approach a minimum.

For this purpose, one must, of course, have the cost of the chief portions of a radio station as a function of some of its dimensions. These data, which are obtained from usual contractors' estimates, may be presented in the form of a curve $S=f(Q)$, where S is the cost and Q the size. For purposes of simplification, one can divide the cost of the whole installation into three principal parts, namely:

Q {

GENERATING APPARATUS AND GROUND CONNECTION:
$S_g=f_1(P)$ where S_g is cost, P power in the antenna.

MASTS:
$S_m=f_2(H)$ where S_m is cost and H is height of transmitting antenna.

ANTENNA:
$S_a=f_3(P, H)$

It is evident that the sum of these quantities is the cost of the whole radio station excluding the buildings and ground, which may, if desired, be included into the equations (Q). In this way, we obtain:

$$S=f_1(P)+f_2(H)+f_3(P,H) \tag{1}$$

[2] "General Electric Review," XXVI, 7, 464, July, 1923.
"Journal of American Institute of Electrical Engineers," XLII, 7, 693, July 1923.

In order to find the minimum of expression (1) graphically, it is necessary to express all the costs as a function of one quantity, for example P, making use of the transmission formula:

$$F = A \frac{h I}{\lambda d} e^{-a d \lambda^{-\delta}} \tag{2}$$

where A, a and δ are the correct coefficients for the given case, the choice of which depend on the nature of the transmission path, F is field intensity at receiving end, I the current in transmitting antenna, λ the wave length, d the distance, and h the effective height of transmitting antenna.

Solving (2) with regard to I, squaring it, and multiplying by the resistance R, we obtain an expression for the power of the transmitting station. The resistance of the antenna R is the sum of two quantities: radiation resistance $R_{\Sigma} = 1580\left(\frac{h}{\lambda}\right)^2$, and the ohmic loss resistance, which we will express in accordance with Mr. Shuleikin's approximate formula[3]

$$R_{\Omega} = R_o \frac{\lambda}{\lambda_o} \tag{3}$$

where R_o is the loss resistance at the fundamental wave length λ_o, hence:

$$P = a + b h^{-2} \tag{4}$$

or, in another form,

$$P = a \left(1 + \frac{R_o \lambda^3}{1580 \lambda_o} h^{-2}\right)$$

where the coefficients have the following values:

$$a = \frac{1580 F^2 d^2 \varepsilon^{2 a d \lambda^{-\delta}}}{A^2} \tag{5}$$

$$b = \frac{R_o F^2 \lambda^3 d^2 \varepsilon^{2 a d \lambda^{-\delta}}}{A^2 \lambda_o} \tag{6}$$

We may transform the last formulas to be applicable to the case of the optimum wave length for a given distance of transmission, which wave length is given by the known equation

$$\lambda_m = (a \delta d)^{1/\delta}.$$

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[3] Radiotechnik," number 14, 416, February, 1921.

Substituting this expression for λ in (5) and (6) we get

$$a_m = \frac{1580\, F^2\, d^2\, \varepsilon^{2/\delta}}{A^2}$$

$$C = \frac{R_o\, F^2\, (\alpha\, \delta)^{3/\delta}\, d^{(2\delta+3)/\delta}\, \varepsilon^{2/\delta}}{A^2\, \lambda_o}$$

If we accept Austin's formula, that is:
$A = 377\ \Omega$, $\alpha = 0{,}0015\ km.^{-1/2}$ and $\delta = 0{,}5$, we get

$$A_{mA} = 0{,}608\ F^2\, d^2; \qquad [W, V, km] \qquad (5a)$$

$$C_{mA} = 6{,}85.10^{-23}\, \frac{R_o\, F^2\, d^8}{\lambda_o}; \qquad [W, V, km] \qquad (6a)$$

$$\lambda_{mA} = 5{,}63.10^{-4}\, d^2 \qquad [km]$$

The effective height of an antenna may be expressed by a coefficient depending on the current distribution (form factor), using any known formula, such as those of Pierce or Shuleikin:

$$h = \gamma\, H$$

where $\gamma = F\,(H, \lambda)$ is form factor.

Hence for a given wave length

$$P = a + C\,[H.\, F\,(H)]^{-2} \qquad (4a)$$

Our next step is to transform the function $S_m = f_2\,(H)$ into the function $S_m = \phi_2\,(P)$, keeping in mind the relation between H and P, which is given by equation (4a).

In order to carry out a transformation, we take a sequence of values S_{m1}, S_{m2}, S_{m3} . . . . ., find their abscissas $H_1, H_2, H_3 \ldots$, and using formula (4a) we calculate the corresponding values P_1, P_2, $P_3 \ldots$, which we lay aside as new abscissas for the same ordinates. In this way we obtain a number of points for the needed curve $\phi_2\,(P)$ (Figure 1).

The cost of the antenna depends upon the power and the height of suspension since, for the same power, if the height is increased, we are obliged to use a larger number of wires to secure the required capacity.

Therefore, to reckon the cost of the antenna as a function of P, it is indispensable to ascertain the corresponding heights H, according to formula (4a), and in this way obtaining $S_a = \phi_3\,(P)$.

In order to determine the minimum cost, it is then sufficient to add the three functions $f_1\,(P)$, $\phi_2\,(P)$, and $\phi_3\,(P)$ graphically, and the minimum will be found on the resulting curve (Figure 1).

However, this will not yet prove the full advantage of the corresponding arrangement, since in most cases the designs are

made to give the least operating expenses of the projected station and not the minimum first cost.

Only in exceptional cases, where only very limited capital is available, is it desirable to be guided by considerations of minimum first cost while being fully prepared for an increase in the operating cost of the service and the consequent decrease of profits.

Therefore, in general, it is necessary to consider methods of calculating the annual operating charges, or, in other words, the

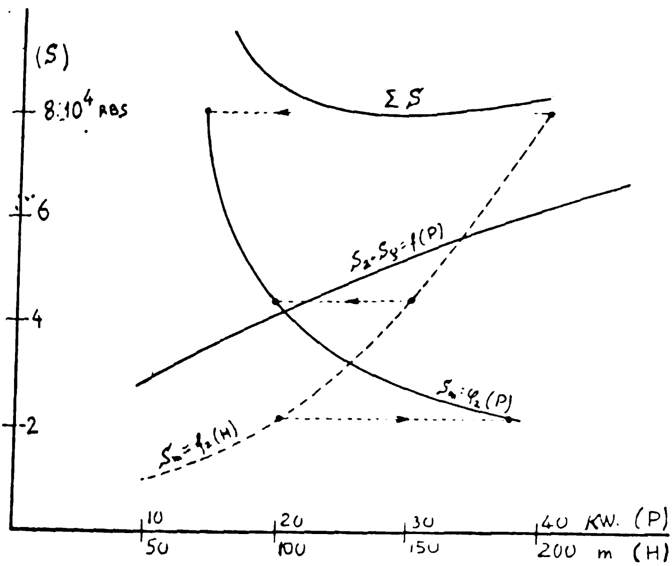

FIGURE 1

cost per word transmitted and the total traffic. For this purpose, each of the curves $S_g = f_1\ (P)$, $S_m = \phi_2\ (P)$, and $S_a = \phi_3\ (P)$ must be multiplied by its correspoding coefficient, in which are taken into consideron amortization, expenses of maintenance, interest on capital, and other expenses which depend on the total value of the station.

If, to the new curves (which differ from the former ones only in scale), we add the curves of annual expenditure for electric power (which is straight line passing thru the origin), and the administration expenses (a straight line of small inclination) and find their sum, we will obtain a curve of annual expenses for the operation of a radio station as a function of power. (The cost of the buildings and ground may also be taken into account.)

The last curve also having a minimum point will, therefore, indicate the most profitable power from the operating profit point of view.

As an example, which illustrates the application of the above method (but which does not pretend to be very precise or strict in treatment), let us determine the relation between the power in the antenna and the height of the masts for a radio station with an effective range of $d=3{,}000$ km., at the optimum wave length, and with a field intensity at the receiving end of $F=20.10^{-3}$ v./km.

For this case, we may accept Dr. L. W. Austin's formula, and therefore $\lambda_{mA}=5.07$ km., and by taking a ratio of 2.5 to 1, as that between the radiated wave length and the natural wave length, of the antenna, we obtain $\lambda_o=2$ km.

Taking into consideration data from stations already built, we may assume $R_o=3\Omega$.

Evaluating coefficients a and b according to formulas (5a) and (6a),

$$a_{mA}=0{,}608\,.\,(20.10^{-3})^2\,3{,}000^2=2{,}190\ W.$$

$$b_{mA}=6{,}85.10^{-23}\frac{3\,.\,(20.10^{-3})^2\,3{,}000^8}{2}=270\ W.\,km^2.$$

Hence

$$P=2190+\frac{270}{h^2} \tag{4b}$$

Let us now take into account the dependence of form factor on the height, according to M. Shuleikin's approximate formula[4]

$$h=H\left(1-\frac{H}{2\,L}\right) \tag{7}$$

where H is height from the ground to the highest point of the antenna, L the length of the vertical and horizontal parts of the antenna (outward in one direction only). This formula is accurate and can be used when $\frac{\lambda}{\lambda_o}\gg 2$, as is the case.

Substituting (7) in (4b) and calculating a sequence of values of P for chosen arbitrary values of H, we get Table I.

At the same time we must determine the cost of wooden masts of the same heights H. As numerical data for the height from the earth to the highest point of the aerial we take those given by A. Shorin.[5]

[4] Previous citation, page 408.
[5] "Telegrafia i telefonia bez provodov," number 16, 599-609 (October, 1922).

The results are also tabulated in Table I.

TABLE I

H (meters)	h (kilometers)	P (watts)	S_m (gold roubles)	
50	0.0470	124,400	10,000	2 masts
100	0.0875	37,400	22,500	3 "
150	0.125	19,500	45,000	4 "
200	0.150	14,400	80,000	4 "

Having the curve $S_m=f_2\ (H)$ (Figure 1), and with the aid of Table I, we draw $S_m=\phi_2\ (P)$ inserting for some values of S_m, instead of H, the corresponding values of P.

Further, we will sum up the cost of all generating and radio frequency machinery and of the antenna erection for several values of P, assuming a tube transmitter, and then draw the sum of curves $S_g=f_1\ (P)$ and $S_a=\phi_3\ (P)$. The sum of the three curves $S_m+S_a+S_g$ gives the total cost, which in this example has the minimum value $S=80{,}000$ roubles, when $P \doteq 30$ kw. and $H=115$ m. (Figure 1).

If we assume the field intensity instead of 20 μv./m. to be 50 μv./m., the minimum cost will be 90,000 roubles with a power of 46 kw. and a height of masts of 88 m.

As is seen from the example given, near the minimum the cost changes very little with changes of power, which fact gives the designer considerable leeway, and at the same time avoids serious errors due to inaccuracy in the preliminary assumptions, such as is inevitable in such calculations.

To determine the minimum operating expenses, let us take on the average 5 percent for amortization as applied to the curves (S_g+S_a), and for the curve S_m-10 percent. We also assume interest on capital for all the curves at 6 percent, and repair expenses (including burnt-out tubes), 4 percent. Then the coefficients by which the cost curves are to be multiplied in order to obtain the yearly expenses will have the following values:

$$\text{for } S_g+S_a-0.15$$

$$\text{for } S_m \quad -0.20$$

We can now calculate the expense of electrical power at the price of 6 copecks kw. hr. for 10 working hours per day at an efficiency of 50 percent.

$$\sigma_p = 365 \,.\, (10)0.06 \frac{P}{0{,}50} = 438\,P \qquad]Roubles, k]$$

Let us draw in Figure 2 the curves

$$\sigma_{g,a} = 0.15\,(S_g + S_a), \quad \sigma_m = 0.2\,S_m, \text{ and } \sigma_p = 438\,P.$$

Summing these up, we get the curve of operating expenses as a function of power (Figure 2); and the curve of administration

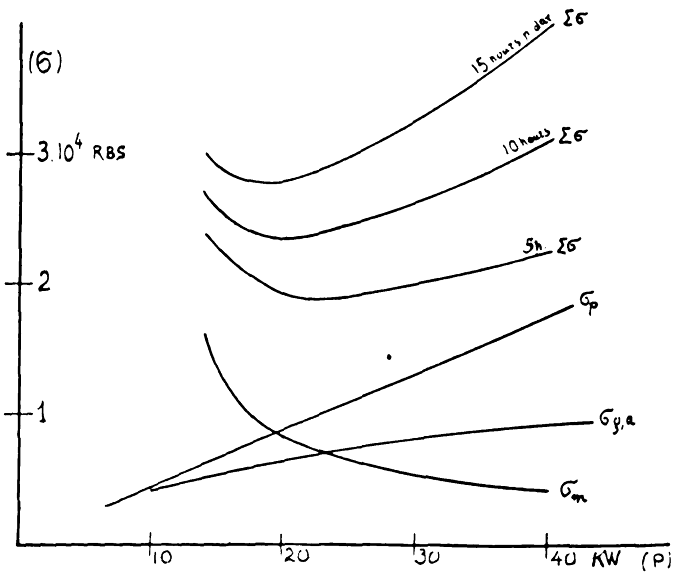

FIGURE 2

expenses, being almost parallel to the axis of abscissas, will not have an appreciable influence on the position of the minimum, and, therefore, may, for simplicity, be neglected.

For comparison, we have drawn also in Figure 2 the operating expenses if the station works 5 or 15 hours per day. As can be seen, the change in traffic of 50 percent leads to a shift of the minimum point on the average of 10 percent.

In this way, for the case of a tube transmitter, we obtain the following feasible values of power:

30 kw. for minimum first cost, and

20 kw. for minimum operating expenses.

As the curve of cost has a flat minimum and the curve of operating expenses a sharper one, we should select a power kw.

and this will increase the initial expenses only 5 percent above the minimum. And finally, the designer should make similar calculations for the arc generator and the radio frequency alternator, and finally choose the most economical and suitable system.

In conclusion, it is to be noticed that the functions $S_m = f_2 (H)$ and $S_g = f_1 (P)$ for the given type of masts and transmitter are applicable with sufficient accuracy in other cases.

Functions $S_m = \phi_2 (P)$ and $S_a = \phi_3 (P)$ only are related specifically to the individual case and must be recalculated for different cases of transmission, since they will then have a different form, depending upon the coefficients a and b in formulas (5) and (6).

SUMMARY: The cost of a radio station may be looked upon as the combined value of the buildings, the generating machinery, and the antenna with its masts and ground connection. It is shown in this paper that, for a given radio transmission, the necessary power P in the antenna and the effective height h of the antenna are connected by an equation $P = a + bh^2$. By means of this formula, the cost of the antenna and the masts, as a function of their dimensions, may be expressed as a function of the power, hence all the curves of cost may be combined graphically. The resulting curve of total cost clearly shows that there is some power for which the cost of a radio transmitter is a minimum.

A method is also given for choice of power by which the annual expenses are a minimum.

The methods described above are illustrated by a determination of the power in the antenna and the heights of the masts for a radio station with a range of 3,000 km. and operating on an optimum wave length of 5,070 m. In this instance, the power for the least outlay is 30 kw. and for the lowest annual expenses, 20 kw.

DISCUSSION ON "POLARIZATION OF RADIO WAVES," BY GREENLEAF W. PICKARD

BY

E. W. ALEXANDERSON

Mr. Pickard mentions in the introduction to his paper that it has been assumed from the inception of the radio art that if the wave was vertically polarized at its origin it would remain so at all distances and that the measurements of Austin and others confirm this assumption. There can be no doubt about the unanimity of opinion that has existed on this subject, but a number of facts have recently been brought out through work on polarization of short waves which leads us to think that the evidence collected in the past may be given a different interpretation.

Extensive systematic measurements undertaken by A. Hoyt Taylor, Austin, and others have shown that direction-finder bearings on long wave stations show great irregularities during the hours of darkness. It has been assumed that these irregularities meant actual change in the direction of wave propagation. We find now in dealing with short waves that such apparent changes in direction of wave propagation can be reproduced regardless of daylight by controlling the plane of polarization of the radiated wave. When a wave is radiated from a horizontal loop, it is found in the immediate neighborhood of the antenna that a direction finder gives bearings at right angles to the direction where the station really is. In other respects, the instrument responds as if it were receiving an ordinary vertically polarized wave. The loop gives maximum response in the vertical position and nearly zero response in the horizontal position. This evidence may be coupled with the experience in aviation practice, according to Capt. W. H. Murphy, that a direction-finder station on the ground may give false indications on an air-plane as great as 45 degrees or more. The false indications have proven to be the greatest if the antenna is allowed

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to trail horizontally, and if the air-plane is flying at right angles to the direction from which bearings are taken. The antenna is therefore held as vertical as possible by a weight and the personnel is instructed to take bearings only when the plane is pointed towards the observing station. In the light of what we now know, these experiences can clearly be interpreted to mean that an antenna trailing at right angles to the line of observation radiates horizontally polarized waves and that the false indications of the direction finder are due to the wave polarization. The inference from this is also that the apparent changes in direction of long waves observed by Taylor and Austin are due to the presence of horizontally polarized wave components. In fact we may say that this apparent change of direction of propagation is a characteristic by which the horizontally polarized wave may be recognized.

It remains to explain why the horizontally polarized wave is received at maximum intensity with the loop in the vertical position. The reason for this is the following:

The electromotive forces of the horizontally polarized wave are parallel to the ground. However, close to the ground we cannot have any difference of potential because of the short circuiting effect of the ground. However, the horizontal electromotive forces are transformed into currents in the ground. These ground currents are at right angles to the true direction of wave propagation. The fact that the loop gives maximum response in vertical position at right angles to the direction of wave propagation is explained by these currents in the ground which are also at right angles to the wave propagation and therefore inductively related to such a loop. From this reasoning, it can be concluded that the false direction indications are to be expected only in the close proximity to the ground. Some measurements have been made which confirm these conclusions. A set of tests was made exploring the characteristics of a wave radiated from a horizontal loop by making frequent measurements to within ten miles of the station. The composite picture which was obtained from this test was a continuously twisting plane of polarization with alternate points of plane and circular polarization. At intermediate points the polarization was eliptical. The plane polarization was indicated by sharp direction bearings and circular polarization by equal intensity from all directions. The observations indicating plane polarization gave bearings sometimes towards the transmitting station and sometimes at right angles.

Besides these measurements around the vertical axis, observations were made with the loop in the horizontal plane. On flat fields the horizontal position gave nearly zero response. At the top of a steep hill and a high bridge the response in the horizontal plane was equal to the vertical.

These results indicate the presence of a horizontal and a vertical wave component with different velocity of propagation. Whenever the two waves are in phase, they give plane polarization. When they are 90 degrees out of phase they give circular polarization. The observation with the loop in the horizontal position on the top of the hill and the bridge show that even a moderate elevation is sufficient with short waves to reach the point where the horizontal electromotive forces are not short-circuited by the ground.

All this leads me to think that horizontal polarization is not confined to short waves only. Direct observation of horizontal polarization at long waves could be made only at great heights, but indirect observations through the effect of ground currents can be made by ordinary direction finders at any wave length. If this theory is correct it means that the irregularities of direction-finder indications recorded by A. Hoyt Taylor and L. W. Austin on long waves can be explained by the presence of horizontally polarized wave components.

DISCUSSION
ON
"THE SHIELDED NEUTRODYNE RECEIVER," BY DREYER AND MANSON

BY

L. A. HAZELTINE

The paper is largely a descriptive one, giving the final results of an admirable engineering development for which Messrs. Dreyer and Manson were mainly responsible. It has seemed that it might be appropriately supplemented by a theoretical discussion of some of the considerations that enter into the electrical design of a receiver employing tuned radio-frequency amplification. The most basic theoretical considerations are those of *sensitivity*, *selectivity* and *fidelity*. By "fidelity" is meant the degree of uniformity with which a band of frequencies is amplified, this band extending on each side of the carrier frequency sufficiently to cover the useful audio frequencies, so that the latter may finally appear with uniform amplification and may thus faithfully reproduce the modulating wave at the transmitter.

All of the above qualities are best illustrated graphically on a *resonance curve*, in which amplification is plotted against frequency: sensitivity is represented by the amplification at the resonant frequency; selectivity, by the falling off in amplification as we depart considerably from the resonant frequency; and fidelity, by the uniformity of amplification in the immediate neighborhood of the resonant frequency.

Let us first derive the equation of the resonance curve. Figure 1a shows the circuit of a single tuned amplifier stage, and Figures 1b and 1c show simplified equivalents. The circuit constants are as follows:

μ, amplification factor of vacuum tube;
g_p, plate conductance of vacuum tube;
L, self-inductance of secondary coil;
C, capacity tuning secondary circuit;
g, conductance of secondary circuit;

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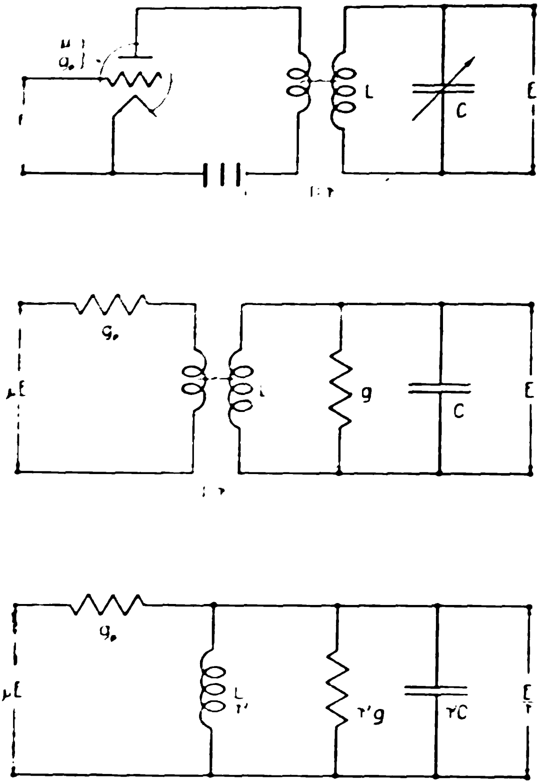
τ, ratio of transformation, secondary to primary;
ω, angular frequency (2π times frequency).*

The amplification is defined as the ratio of the output vol-



FIGURES 1a, 1b, 1c—One-Stage Vacuum-Tube Amplifier and Simplified Equivalent Circuits

tage E' to the input voltage E. If these voltages are expressed as complex quantities $\mathbf{E'}$ and $\mathbf{E}$, the amplification is

*NOTES: It is convenient in vacuum-tube calculations to use conductances rather than resistances, and conductances often vary less rapidly with variations in frequency; if r is the total series resistance of the secondary tuned circuit, then $g = \frac{r}{\omega^2 L^2} = \frac{Cr}{L}$. It is assumed that the primary and secondary coils are closely coupled, in which case τ is the ratio of turns; otherwise τ may be taken as the ratio of secondary self-inductance L to the mutual inductance—that is, to the voltage ratio. It is also assumed that the primary capacity is negligible; otherwise it can be added directly to $\tau^2 C$. The combined effect of the primary capacity (or of g_o) with looseness of coupling, if considerable, requires a more elaborate derivation. It is also assumed that regeneration has been eliminated, by removing or neutralizing all couplings between the input and output circuits, except, of course, the mutually conductive coupling of the vacuum tube.

also a complex quantity A, and includes the phase difference between the voltages as well as the ratio of their magnitudes:

$$A = \frac{E'}{E}. \tag{1}$$

Directly from Figure 1c, since the same current flows through g_p as through the parallel group, L/τ^2, $\tau^2 g$, $\tau^2 C$, we have the ratio of voltages equal to the ratio of the corresponding impedances:

$$\frac{\frac{E'}{\tau}}{\mu E} = \frac{\dfrac{1}{\tau^2 g + \dfrac{\tau^2}{j\,\omega\,L} + j\,\omega\,\tau^2 C}}{\dfrac{1}{g_p} + \dfrac{1}{\tau^2 g + \dfrac{\tau^2}{j\,\omega\,L} + j\,\omega\,\tau^2 C}} = \frac{g_p}{g_p + \tau^2 g + \dfrac{\tau^2}{j\,\omega\,L} + j\,\omega\,\tau^2 C} \tag{2}$$

Substituting in (1),

$$A = \frac{E'}{E} = \frac{\tau\,\mu\,g_p}{g_p + \tau^2 g + j\,\tau^2\left(\omega\,C - \dfrac{1}{\omega\,L}\right)} = \frac{\tau\,\mu\,g_p}{g_p + \tau^2 g + \dfrac{j\,\tau^2}{\omega_o\,L}\left(\dfrac{\omega}{\omega_o} - \dfrac{\omega_o}{\omega}\right)} \tag{3}$$

where

$$\omega_o = \frac{1}{\sqrt{C\,L}} \tag{4}$$

is the resonant angular frequency. Instead of the angular frequency ω, let us use as the variable the natural logarithm,

$$x = \log_\varepsilon \frac{\omega}{\omega_o}. \tag{5}$$

Then

$$\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega} = \varepsilon^x - \varepsilon^{-x} = 2\,\sinh x; \tag{6}$$

and

$$A = \frac{\tau\,\mu\,g_p}{g_p + \tau^2\,g + \dfrac{j\,2\,\tau^2}{\omega_o\,L}\,\sinh x} \tag{7}$$

Ordinarily we are not interested in values of x greater than about 0.1, for which $\sinh x$ is very nearly equal to x; so to a very close approximation*.

*The use of natural logarithms for the frequency scale is convenient; for to a high degree of approximation x represents directly the deviation in frequency referred to the mean of the two frequencies,

$$x = \frac{\omega - \omega_o}{\dfrac{\omega + \omega_o}{2}} \tag{9}$$

—that is, a value of x equal to 0.1 means that the two frequencies under consideration differ by 0.1 or 10% of their mean. Equation (8) happens to be

$$A = \frac{\tau \mu g_p}{g_p + \tau^2 g + \frac{j\, 2\, \tau^2 x}{\omega_o L}}. \tag{8}$$

The amplification at resonance ($x = 0$) is

$$A_o = \frac{\tau \mu g_p}{g_p + \tau^2 g}. \tag{11}$$

Hence

$$A = \frac{A_o}{1 + \frac{j\, 2\, \tau^2 x}{\omega_o L (g_p + \tau^2 g)}} \tag{12}$$

Let us substitute the power factor* of the circuit combination g_p, g, L.

$$p = \frac{\omega_o L}{\tau^2}(g_p + \tau^2 g) = \frac{\omega_o L\, g_p}{\tau^2} + \omega_o L\, g = p_p + p_t, \tag{13}$$

where p_p and p_t are respectively the power factors of the combinations g_p, L and g, L. Then

$$A = \frac{A_o}{1 + \frac{j\, 2\, x}{p}} \tag{14}$$

The magnitude of the amplification per stage is then

$$A = \frac{A_o}{\sqrt{1 + \left(\frac{2\, x}{p}\right)^2}} = \frac{\tau \mu g_p}{g_p + \tau^2 g} \cdot \frac{1}{\sqrt{1 + \left(\frac{2\, x}{p}\right)^2}} \tag{15}$$

For purposes of plotting, it is desirable to express amplification on a logarithmic scale — say in transmission units:

Logarithmic amplification per stage,

$$20\, log_{10} A = 20\, log_{10} \left\{ \frac{\tau \mu g_p}{g_p + \tau^2 g} \cdot \frac{1}{\sqrt{1 + \left(\frac{2\, x}{p}\right)^2}} \right\}$$

$$= 20\, log_{10} \frac{\tau \mu g_p}{g_p + \tau^2 g} - 10\, log_{10} \left[1 + \left(\frac{2\, x}{p}\right)^2 \right] \; T.\ U. \tag{16}$$

exact if x represents the deviation in frequency referred to the harmonic mean frequency,

$$x = \frac{\omega - \omega_o}{\frac{2\, \omega\, \omega_o}{\omega + \omega_o}}. \tag{10}$$

*The writer ventures to suggest that such a quantity as defined by (13) be called the *natural power factor* of the resonant circuit as a whole; for it is the ratio of the conductance to the natural admittance, or of the resistance to the natural impedance. The term is in accordance with the definition of power factor in general, which may be expressed as the ratio of a resistance to an impedance, and should be no more confusing than is the term *natural impedance* as applied to a resonant circuit as a whole.

Figure 2a shows plots of this equation for various values of τ, and with the values of μ, g_p, g and $\omega_0 L$, given in the margin. With $\tau = 1$ (which is equivalent to a direct tuned reactance coupling), we see that the amplification at resonance is 16.1 T.U., which represents good sensitivity for one stage; and the amplification is practically constant up to $x = 0.005$, which means practically perfect fidelity (this corresponds to a side frequency 3 kc. per sec. from a carrier frequency of 600 kc. per sec., or 500 m. wavelength). But there is still considerable amplification (6.1 T.U.) at frequencies 10 per cent off resonance ($x = 0.1$); so the selectivity is poor. When the primary turns are reduced so that $\tau = \sqrt{2}$, the resonant amplification rises to 17.5 T.U., still with practically perfect fidelity, but with a drop in amplification at 10 percent off resonance to 3.4 T.U. Thus we have gained both in sensitivity and selectivity, without impairing fidelity. The same is true when we raise τ to 2, but beyond this value there is a loss in sensitivity, at first slow and then more rapid. The selectivity increases at first rapidly and then approaching a limit, as the curves approach the same form. The fidelity becomes slightly impaired and likewise approaches a limit. These results are given numerically in Table I.

TABLE I

Summary from Figure 2a. Values in Transmission Units

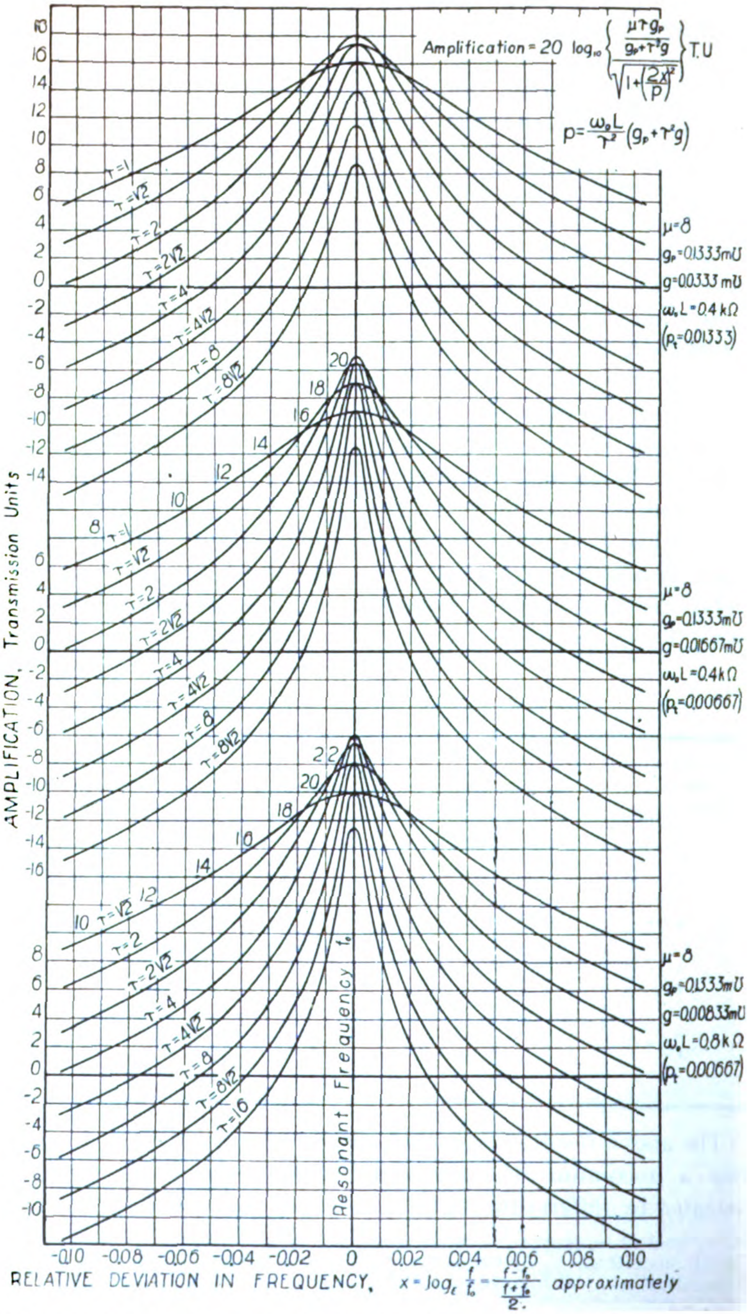
Transformation Ratio,	Sensitivity— Amplification At Resonance	Selectivity— Drop in Amplification 10% off Resonance	Fidelity— Drop in Amplification 0.5% off Resonance
1	16.1	10.0	0.1
$\sqrt{2}$	17.5	14.1	0.3
2	18.1	17.6	0.6
$2\sqrt{2}$	17.5	20.0	1.0
4	16.1	21.6	1.3
$4\sqrt{2}$	14.0	22.5	1.6
8	11.5	23.0	1.8
$8\sqrt{2}$	8.8	23.3	1.85
∞	∞	23.5	1.9

The above results show that there exists a value of τ which gives a maximum resonant amplification A_0. This may be evaluated by differentiating (11):

$$0 = \frac{dA_0}{d\tau} \quad \text{or} \quad 0 = \frac{d}{d\tau}\left(\frac{g_p + \tau^2 g}{\tau}\right) = -\frac{g_p}{\tau^2} + g \tag{17}$$

or

$$g_p = \tau^2 g \quad \text{or} \quad \tau = \sqrt{\frac{g_p}{g}} \tag{18}$$



FIGURES 2a, 2b, 2c—Families of Resonance Curves for One-Stage Amplifier with Various Circuit Constants

The maximum resonant amplification is then

$$A_o = \frac{\tau \mu g_p}{2 g_p} = \frac{\tau \mu}{2} = \frac{\mu}{2}\sqrt{\frac{g_p}{g}}. \tag{19}$$

With the constants of Figure 2a, the turns ratio for maximum A_o is, as indicated by the curves, $\tau = \sqrt{\frac{0.1333}{0.0333}} = 2.$

Under the most common conditions, especially at the higher frequencies and with a small number of stages, the matter of fidelity does not impose a limitation on τ. The best value of τ is then determined as a compromise between sensitivity and selectivity.* Since selectivity increases continuously with increasing τ, while sensitivity passes through a maximum, the best value of τ is higher than that corresponding to maximum sensitivity, and therefore, by (18), is such that the input conductance $\tau^2 g$ of the transformer at resonance is substantially higher than the plate conductance g_p of the vacuum tube. In the table, the best value of τ evidently lies between 2 and 4. The intermediate value, $2\sqrt{2}$, together with the other constants of Figure 2a, corresponds roughly, at the lower broadcast frequencies, to the receiver which formed the subject of the paper under discussion. It is believed that the Neutrodyne receivers were the first to thus obtain increased selectivity by employing fewer primary turns than correspond to maximum amplification at resonance.

Besides the turns ratio τ, the designer has under his control, within certain limits imposed largely by cost and bulk, the self-inductance L and the conductance g of the coil. Figure 2b shows resonance curves comparative with those of Figure 2a, in which g has been halved, by minimizing the sources of loss in the tuned circuit. The two sets of curves are practically identical about 10 percent off resonance, but the resonant amplification has been increased. The result is a gain in sensitivity and in selectivity, but some impairment in fidelity. Also, the turns ratio for maximum resonant amplification has been increased to $2\sqrt{2}$, in accordance with (18).

If in the curves of Figure 2b the lower conductance g causes fidelity to be a limitation, and the turns ratio has to be lowered so as to give the same fidelity as in Figure 2a, then the selectivity will be the same as in Figure 2a, but there will remain some

*This is on the assumption that stability does not impose a limitation. In designs giving a low power factor p_t at high frequencies, the possibility of instability, due mainly to variations in the coupling capacities of vacuum tubes as manufactured, may make it desirable to use fewer primary turns.

gain in sensitivity. However, this gain may be insufficient to offset the greater cost of the low-loss coil, since low losses entail greater bulk. It just happens that at the low broadcast frequencies (in the neighborhood of 600 kc. per sec.), fidelity begins to be a limitation with coils of ordinary size (3 in. in greatest dimension).

In Figure 2c are shown resonance curves for the same transformer power factor p_t, but with twice the self-inductance L and therefore half the conductance g and tuning capacity C. These curves are identical in form with those of Figure 2b, provided comparison is made between curves in Figure 2c having $\sqrt{2}$ times the value of τ for the curves in Figure 2b, but are displaced upward by 3.0 T.U. $(=20\, log_{10}\sqrt{2})$. Thus with the proper increase in turns ratio, there has been an increase in sensitivity with no change in selectivity nor in fidelity. The value of L in practice is determined by the upper limit of the broadcast frequency range and by the minimum tuning capacity, which latter should therefore be kept as low as is feasible, considering the natural capacities of the vacuum tube and the wiring.

The curves of Figures 2a, 2b and 2c illustrate certain other facts to which attention should be drawn. First, the amplification near 10 percent off resonance and beyond is practically independent of the transformer conductance g; for when $2x/p$ is large, equation (15) reduces to

$$A = A_o \frac{p}{2\,x} = \frac{\tau\,\mu\, g_p}{g_p + \tau^2\, g} \cdot \frac{\omega_o\, L\,(g_p + \tau^2\, g)}{2\,\tau^2\, x} = \frac{\mu\, g_p\, \omega_o\, L}{2\,\tau\, x}. \qquad (20)$$

The variation of g with frequency consequently has a negligible effect on the resonance curve.

Again, the logarithmic amplification with customary values of the circuit constants falls below zero within the value $x = 0.1$, —that is, each stage of a tuned radio-frequency amplifier actually weakens an interfering signal which is 10 percent or more off resonance. This means that such an interfering signal, as picked up by a small antenna, may reach the detector circuit so attenuated as to be weaker than the signal picked up by the detector circuit directly. The loss in actual selectivity consequent on such direct pick-up in intermediate circuits is one of the important reasons for shielding, as brought out in the paper.

We will now consider the effect of varying the number of stages of amplification. If all stages are alike, the total amplification in transmission units will be directly proportional to the number of stages n, as given by the equation

$$20 \log_{10} A^n = 20\, n \log_{10} \left\{ \frac{\tau \mu g_p}{g_p + \tau^2 g} \cdot \frac{1}{\sqrt{1 + \left(\frac{2x}{p}\right)^2}} \right\} T.U. \tag{21}$$

The amplification relative to that at resonance is also proportional to n:

$$20 \log_{10} \frac{A^n}{A_o{}^n} = -10\, n \log_{10} \left[1 + \left(\frac{2x}{p}\right)^2 \right] T.\ U. \tag{22}$$

Using the circuit constants of Figure 2c and the turns ratio corresponding to maximum resonant amplification, this relative amplification is plotted for various values of n in Figure 3a; and the resonant amplification is given for each value of n in the left-hand part of Table II. The total amplification would be obtained by shifting each curve upward by the respective resonant amplification.

TABLE II

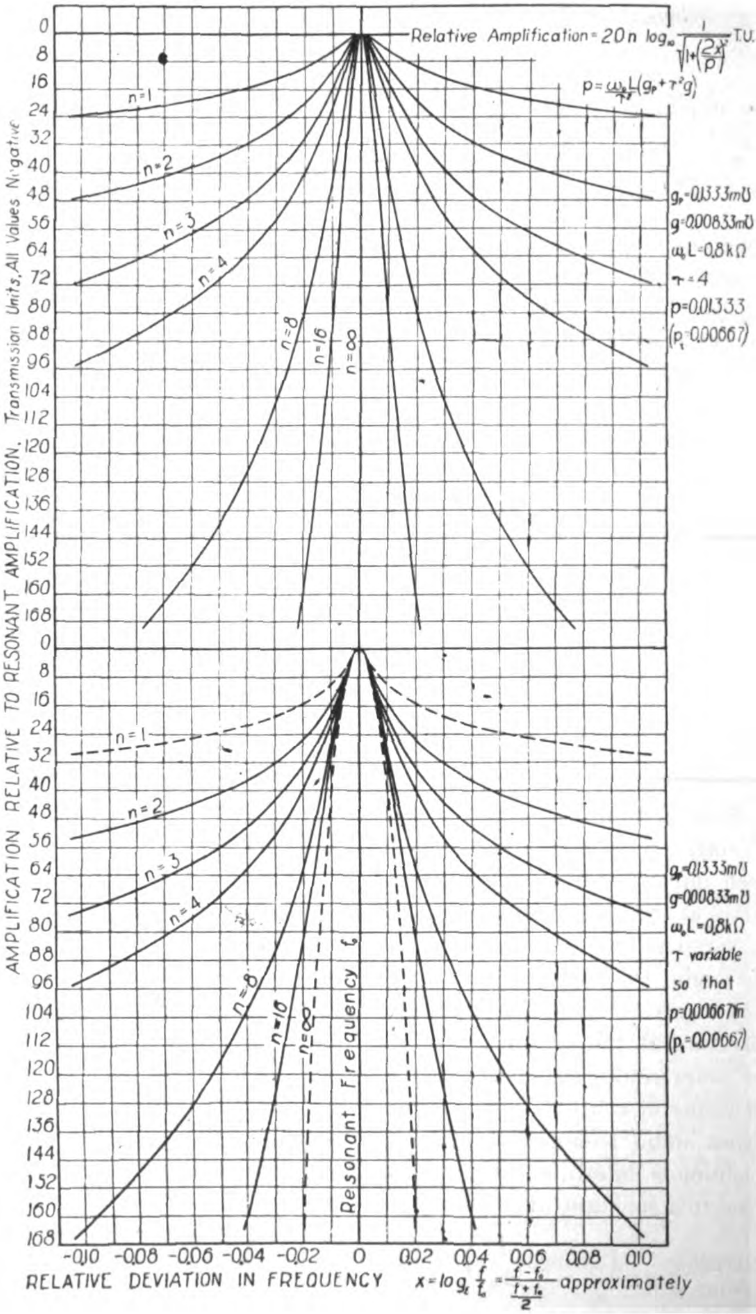
Resonant Amplification, Transmission Units

Number of Stages n	With Constant Turns Ratio, Figure 3a: Turns Ratio τ	Amplification, Per Stage, t.u.	Amplification, Total, t.u.	With Constant Fidelity, Figure 3b: Turns Ratio τ	Amplification, Per Stage, t.u.	Amplification, Total, t.u.
1	4	24.1	24.1	∞	− ∞	− ∞
2	4	24.1	48.2	6.21	23.3	46.5
3	4	24.1	72.2	4.67	24.0	71.9
4	4	24.1	96.3	4	24.1	96.3
8	4	24.1	192.6	2.96	23.7	189.6
16	4	24.1	383.3	2.31	22.8	365.6
∞	4	24.1	∞	0	− ∞	− ∞

Examination of Figure 3a shows that increasing the number of stages proportionately increases the selectivity, but with some impairment in fidelity, the curvature of the resonance curves at the origin becoming sharper. If we correct this effect by varying the turns ratio so as to have constant curvature at the origin, the curves of Figure 3b are obtained, the curve for four stages being taken the same as in Figure 3a. Constant curvature at the origin means practically constant fidelity for the lower audio frequencies (the curves practically coinciding for values of x up to 0.003) and nearly constant fidelity for the higher audio frequencies. The proper turns ratio τ for this condition is determined by making the second derivative of (22) equal to a constant at $x=0$;

$$const. = \frac{d^2}{d x^2}\left(20 \log_{10} \frac{A^n}{A_o}\right) = -10\, n \frac{d^2}{d x^2} \log_{10} \left[1 + \left(\frac{2x}{p}\right)^2\right] \tag{23}$$

$$= -\frac{10}{2.30} \cdot \frac{8n}{p^2} \cdot x = 0 \tag{24}$$



FIGURES 3a and 3b—Families of Resonance Curves for Multistage Amplifier, with Like Stages and with Unlike Stages Respectively

Hence, if p_1 is the value of the power factor p that would give the desired fidelity with one stage $(n=1)$,

$$\frac{1}{p_1^2}=\frac{n}{p^2} \quad \text{or} \quad p=p_1\sqrt{n} \tag{25}$$

that is, the turns ratio τ must be varied so that the power factor is proportional to the square root of the number of stages; it is given by equation (13):

$$\tau^2=\frac{\omega_o L g_p}{p-\omega_o L g}=\frac{\omega_o L g_p}{p_1\sqrt{n}-\omega_o L g} \tag{26}$$

The resonant amplification by (11) is then

$$A_o=\frac{\tau \mu g_p}{g_p+\tau^2 g}=\frac{\mu}{p}\sqrt{\omega_o L g_p (p-\omega_o L g)}\ \sqrt{\omega_o L g_p (p_1\sqrt{n}-\omega_o L g)}$$

$$=\frac{\mu}{p_1\sqrt{n}} \tag{27}$$

These equations were used to obtain the values of turns ratio and amplification given in the right-hand part of Table II.

The curves of Figure 3b are plotted from equation (22), as in Figure 3a, but with p given by (25):

$$20\, log_{10}\frac{A^n}{A_o^n}=-10\, n\, log_{10}\left[1+\left(\frac{2x}{p_1\sqrt{n}}\right)^2\right] T.\,U. \tag{28}$$

It is interesting to note that this equation approaches a finite limit as n approaches infinity, this being evaluated as follows:

$$20\, log_{10}\frac{A^n}{A_o^n}=-\frac{10\, n}{2.30}\, log_e\left[1+\left(\frac{2x}{p_1\sqrt{n}}\right)^2\right]$$

$$=-\frac{10\, n}{2.30}\left\{\left(\frac{2x}{p_1\sqrt{n}}\right)^2-\frac{1}{2}\left(\frac{2x}{p_1\sqrt{n}}\right)^4+\cdots\right\}$$

$$=-\frac{10}{2.30}\left(\frac{2x}{p_1}\right)^2 T.\,U.\; n=\infty \tag{29}$$

This limit is the dotted parabola of Figure 3b, which the other curves are seen to approach for a greater and greater range as n is increased.

The most important fact illustrated in Figure 3b is that *with constant fidelity the selectivity is increased as the number of stages is increased*, whereas with a fixed number of stages selectivity can be increased beyond a certain point only at the expense of fidelity. With constant fidelity, the selectivity in each stage is decreased as the number of stages is increased, and the possible increase in over-all selectivity has a finite limit, which, however, is far beyond what is attainable with any practicable number of stages (that is, in Figure 3b, the curve for $n=4$, or even that for

$n=8$, differs widely from that for $n=\infty$, except very close to the resonant frequency).

Table II shows that, with any practicable number of stages greater than one, the resonant amplification per stage does not vary greatly with the number of stages, for constant fidelity. It just happens that with the data chosen, the transformer power factor p_t is equal to the total power factor p_1 for one stage; so the number of primary turns approaches zero and the amplification approaches infinite attenuation with one stage. For this reason the curve for $n=1$ in Figure 3b has been shown dotted, as representing a limit rather than a practical condition with the data chosen. With other data, the desired fidelity with one stage might not be even approached ($p_t > p_1$), or it might be attained with finite attenuation or even with some amplification ($p_t < p_1$). As the number of stages is increased above one, the resonant amplification per stage first increases to a maximum (corresponding to the condition of equation (18), and then falls. The total amplification rises nearly in proportion to the number of stages for all practicable numbers, but for very large numbers of stages it also reaches a maximum and then falls, ultimately becoming an attenuation which approaches infinity. That these latter conditions are purely academic is shown by the calculations that the total amplification does not reach its maximum until a few thousand stages are employed and does not become an attenuation until the number of stages passes a million!

Summing up with respect to the resonance curves, equation (21) when written in the form

$$20\, log_{10} A'' = 20\, n\, log_{10} \frac{A_o}{\sqrt{1+\left(\frac{2\,x}{p}\right)^2}}$$

$$= 20\, n\, log_{10} A_o - 10\, n\, log_{10}\left[1+\left(\frac{2\,x}{p}\right)^2\right] \qquad (30)$$

shows that all resonance curves, when plotted to logarithmic scales as illustrated, are alike in form and differ only in scale and in position. Of the three parameters, p determines the horizontal scale, n determines the vertical scale, and A_o determines the position of the curve in the vertical direction.

The above discussion of selectivity refers to selection against interfering signals of fixed frequency, as other broadcasting stations. Interference from damped-wave stations, atmospheric and other strays, is essentially different in that the interfering

waves have a wide band of frequencies, and the main interference is due to components *at and near the resonant frequency of the receiver.* In the case of random interference, as from strays, it may most reasonably be assumed that on the average the interfering waves are uniformly distributed in intensity over the narrow frequency band covered by a sharply tuned receiver, and the same is nearly true of damped telegraph waves. On the basis of this assumption, John R. Carson has discussed* the subject of random interference and has derived certain formulas representing relative signal-stray ratios. Carson makes comparisons, in effect, by integrating the square of the amplification with respect to frequency between the side-band limits for the signal and between infinite limits for the strays:

$$\frac{\int_{-x}^{x} A^{2n}\,dx}{\int_{-\infty}^{\infty} A^{2n}\,dx}=\frac{2A_o^{2n}\int_o^x \frac{dx}{\left[1+\left(\frac{2x}{p}\right)^2\right]^n}}{2A_o^{2n}\int_o^\infty \frac{dx}{\left[1+\left(\frac{2x}{p}\right)^2\right]^n}}=\frac{\int_o^{\frac{2x}{p}} \frac{d\left(\frac{2x}{p}\right)}{\left[1+\left(\frac{2x}{p}\right)^2\right]^n}}{\int_o^\infty \frac{d\left(\frac{2x}{p}\right)}{\left[1+\left(\frac{2x}{p}\right)^2\right]^n}} \tag{31}$$

On the supposition that the fidelity is practically perfect, $(2x/p)^2$ is small compared with unity and the numerator reduces to $2x/p$. The denominator integrates to

$$\int_o^\infty \cos^{2n-2}\theta\,d\theta=\frac{1.3.5\ldots.(2n-3)}{2.4.6\ldots.(2n-2)}\cdot\frac{\pi}{2}=\frac{(2n-2)!}{2^{2n-2}(n-1)!^2}\cdot\frac{\pi}{2}$$

Substituting these expressions, (31) becomes

$$\frac{\int_{-x}^{x} A^{2n}\,dx}{\int_{-\infty}^{\infty} A^{2n}\,dx}=\frac{2x}{p}\cdot\frac{2^{2n-2}(n-1)!^2}{(2n-2)!}\cdot\frac{2}{\pi}$$

$$=\frac{2x}{p_1\sqrt{n}}\cdot\frac{2^{2n-2}(n-1)!^2}{(2n-2)!}\cdot\frac{2}{\pi} \tag{32}$$

the last form being useful if fidelity is to remain constant, as discussed in connection with Figure 3b. In this expression $2x/p_1$ has some small value, fixed by the fidelity desired, x being the useful side-band limit. The only variable over which we have control is n. Table II shows how the variable part of (32) de-

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* "Bell System Technical Journal," vol. 2, number 3, p. 28 (1923), and "Trans A. I. E. E.," vol. 43, p. 79 (1924).

pends on n. Evidently, on the basis of Carson's theory, there is no considerable gain in increasing the number of stages above two.

TABLE III

Number of Stages n	Relative Signal-Stray Ratio $\dfrac{2^{2n-2}(n-1)!^2}{\sqrt{n}(2n-2)!}$
1	1
2	1.41
3	1.54
4	1.60
8	1.69
16	1.73
∞	$\sqrt{\pi}=1.77$

Let us examine the question of strays in greater detail. Any audio-frequency response may be analysed into components of various frequencies, each of which components is due to beats between radio-frequency waves whose frequencies differ by the audio frequency. When a signal wave is absent, strays will be heard due to the beats between their various components. When a signal wave is present, there will in addition be beats between the strays and the components of the signal wave, mainly the carrier wave.

Under tolerable receiving conditions, beats between the carrier wave and the strays are more important than beats between different components of the strays, as these components, even in the aggregate, will be weaker than the carrier. Those components of the strays whose frequencies are very close to the carrier will result in low-frequency audio disturbances. Components more remote from the carrier in frequency will result in audio disturbances of higher frequency (hisses) or in disturbances beyond the limit of audibility. Carson's theory does not go so far as to consider the relative importance of different audio frequencies, and should be supplemented by the use of a factor equal to the relative sensitivity of the ear at different frequencies. More crudely, we may substitute a factor which is equal to unity up to a certain frequency, about 10 kilocycles per sec., and is equal to zero above this value. This means that the integral in the denominator of (31) should have as its upper limit a value of x corresponding to about 10 kc. instead of infinity. This will make no great difference if the resonance curve is sharp; but with a broad resonance curve it will make the relative signal-stray ratio dependent solely on the ratio of the width of the useful audio-frequency band to the width of

the total audible band. Since it is hardly possible to make the resonance curve suitably sharp at all frequencies with the broadcast range, we are led to the conclusion that *the only effective way to minimize strays over the range of a receiver is to so design the audio frequency amplifier and loud-speaker as to pass only the useful audio frequencies and to attentuate all higher audible frequencies.** This is one of the important purposes of the condensers shunting the audio-frequency transformers and the loud-speaker, in the receiver described in the paper. The hissing type of stray is thus largely eliminated; but the low-frequency type is quite unavoidable, as it has no feature to distinguish it from the signal.

The less important mode of occurrence of stray interference, the beats between different components of the strays, is more complicated in theoretical treatment. To find the interference at any particular audio frequency, we should take two resonance curves displaced by that frequency (as in Figure 4a, but using actual, instead of logarithmic, amplification), multiply their ordinates squared, and integrate between infinite limits. This process discriminates against the higher audio frequencies, which confirms the practical observation that the high-frequency hissing strays are less conspicuous in the absence of a carrier wave. Stray interference of this sort can be minimized with respect to *all* audio frequencies by employing sharp resonance curves. Audio-frequency selection is still helpful (though not so important as in the case considered in the preceding paragraph, on account of the lesser importance of hissing strays), but it can no longer make up for broadness in the resonance curve.

*It may be remarked in this connection that the derivation of the amplification equation given previously applies to audio frequency as well as to radio frequency, provided that the assumptions stated at the beginning hold good. However, the value of x will not be small over the audio-frequency range; so the exact equation (7) must be used instead of (8), giving for the logarithmic amplification with n stages the following expression in place of (21):

$$20 \log_{10} A^n = 20\, n \log_{10} \left\{ \frac{\tau \mu g_p}{g_p + \tau^2 g} \cdot \frac{1}{\sqrt{1+\left(\frac{2}{p} \sinh x\right)^2}} \right\} T.\,U. \qquad (33)$$

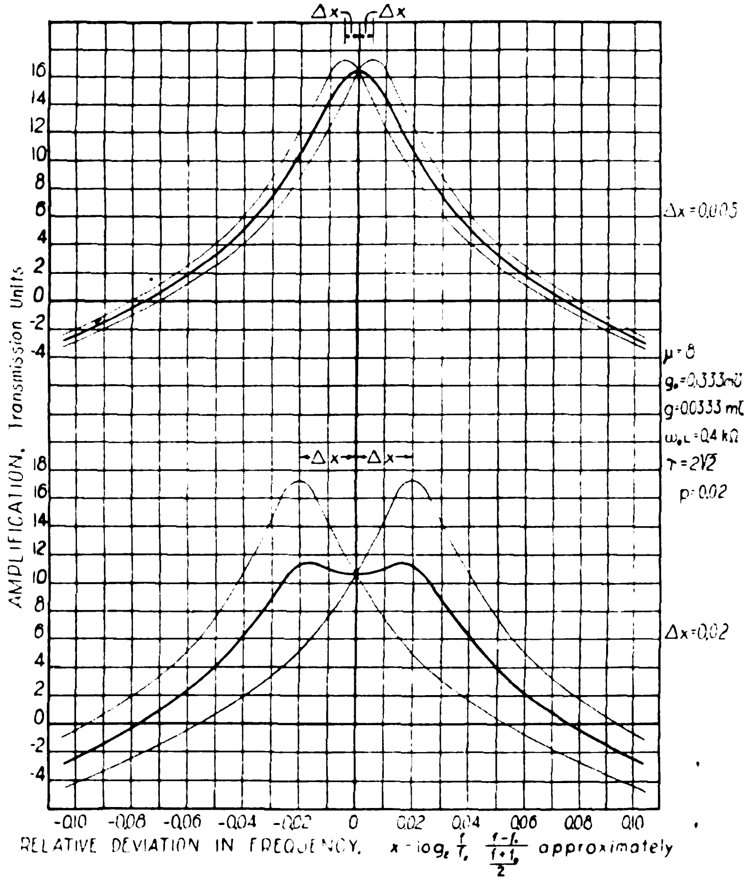
To give a flat curve, p is made large, primarily by employing such a low value of τ that $\tau^2 g$ is much less than g_p. In this case, (33) reduces to

$$20 \log_{10} A^n = 20\, n \log_{10} \frac{\tau \mu}{\sqrt{1+\left(\frac{2}{p} \sinh x\right)^2}}\ T.\,U \qquad (34)$$

in which p is substantially

$$p = \frac{\omega_0 L g_p}{\tau^2} = \frac{g_p}{\tau^2}\sqrt{\frac{L}{C}} \qquad (35)$$

We will now consider the effects on the resonance curve of an amplifier of slight lack of resonance in the different stages, due in particular to accidental misalignment of the condensers when a common control is employed, as in the receiver under discussion. If we have two like stages, with resonant frequencies displaced Δx each side of the mean, their resonance curves plotted with their mean frequency as the datum will appear as shown by the light curves in Figure 4a, where $\Delta x = 0.005$. The



FIGURES 4a and 4b—Resonance Curves Illustrating Effect of Detuning

average amplification per stage is the mean between these curves, as shown by the heavy curve. This evidently is very nearly identical with the original curves except near its peak, which is lower and slightly broader. There is thus some loss in sensitivity and in selectivity, with a slight gain in fidelity.

The loss in amplification per stage at the mean resonant frequency may be calculated by substituting Δx for x in the expression for relative amplification, and is

$$10 \log_{10}\left[1+\left(\frac{2\Delta x}{p}\right)^2\right] T.\ U. \tag{36}$$

which, for the data of Figure 4a, gives

$$10 \log_{10}\left[1+\left(\frac{2\times 0.005}{0.02}\right)^2\right] = 1.0\ T.\ U.$$

as indicated on Figure 4a. For the very small misalignments that would be tolerated in practice ($\Delta x < 0.005$), the expression (36) may be put in the simpler form

$$10 \log_{10}\left[1+\left(\frac{2\Delta x}{p}\right)^2\right] = \frac{10}{2.30} \log_e\left[1+\left(\frac{2\Delta x}{p}\right)^2\right]$$
$$= \frac{10}{2.30}\left(\frac{2\Delta x}{p}\right)^2 \text{ approx.} \tag{37}$$

which shows that the loss in amplification varies as the square of the deviation in resonant frequency. This expression shows also that the permissible value of Δx is proportional to the power factor p, which is one of the reasons given in the paper for employing a design giving a relatively broad resonance curve, —that is, a relatively high value of p.

With more than two stages and a given maximum frequency deviation Δx, the most adverse condition would be for half of the stages to be at one extreme ($+\Delta x$) and the other half at the other extreme ($-\Delta x$). The average amplification per stage would then still be represented by Figure 4a; and equations (36) and (37) would still apply. If, on the other hand, the misalignments were uniformly distributed between ($-\Delta x$) and ($+\Delta x$), the lowering in the peak amplification would only be one-third as great, one-third being the ratio of the average value to the maximum value with a square-law relation, as in (37). In practice, with a given tolerance, the misalignments will be distributed according to probability laws, and the average lowering in the peak amplification per stage will be less than one-third the value indicated by (37). It should be noted that the percentage deviation in capacity is *twice* the percentage deviation in resonant frequency; so the value $\Delta x = 0.005$ corresponds to capacity deviations 1 percent from the mean, which is much more than is tolerated in the receiver under discussion.

Figure 4b shows the effect of a greater deviation in resonant frequency, $\Delta x = 0.02$, such as might occur in a receiver having

separate tuning controls when detuning is employed for volume control of the signal. Here the resultant curve has considerably changed its form, showing two peaks. This affects fidelity in that there is a slight tendency to accentuate the higher audio frequencies in place of the usual and more desirable condition of discriminating against them. With the data chosen, the loss in amplification at the mean of the resonant frequencies is

$$10 \log_{10}\left[1+\left(\frac{2\times 0.02}{0.02}\right)^2\right]=7.0\ T.\ U.$$

Evidently in Figure 4b, there has been a large loss in selectivity, so the practice of detuning for volume control is dangerous.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued March 9, 1926-May 4, 1926

By

JOHN B. BRADY

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,575,824—C. H. EIFFERT, filed October 27, 1922, issued March 9, 1926. (Of Roanoke, Virginia.)
RECEIVING ANTENNA FOR RADIO TELEGRAPHY OR TELEPHONY, comprising a device which may be screwed into the usual electric light socket for establishing capacitive connection with the lighting line.

1,575,980—W. S. FERDON, filed August 8, 1923, issued March 9, 1926. (Of Omaha, Nebraska.)
RADIO COMMUNICATION, wherein an antenna device is enclosed in a tube and arranged for the radiation of high frequency current exterior to the tube.

1,576,162—A. F. VAN DYCK, of Schenectady, New York. Filed March 31, 1922, issued March 9, 1926. Assigned to General Electric Company.
HIGH FREQUENCY APPARATUS, wherein electron tubes and associated circuits are housed within a cabinet having a hinged door thereon with apertures through which the controls for various parts of the electron tube circuits pass in such manner that the door of the cabinet may be opened without removing the control knobs.

1,576,324—JAMES B. HOGE and EDWARD E. CLEMENT, of Washington, D. C. Filed August 22, 1922, issued March 9, 1926. Assigned to Edward F. Colladay.
RADIOPHONE BROADCASTING SYSTEM, in which a telephone network is employed for determining from the transmitting station whether or not the receiving apparatus at the different subscribers' stations is operating at resonance with the transmitting frequency.

1,576,667—J. O. MAUBORGNE and GUY HILL, of Washington, D. C. Filed February 9, 1924, issued March 16, 1926.
SYSTEM FOR ELIMINATING INTERFERENCE, in which a wave coil is employed for responding to the transmitted frequency without interference from undesired frequencies.

1,576,783—JOHN B. PITTS, of Winnetka, Illinois. Filed January 31, 1925, issued March 16, 1926.
RADIO DETECTOR of the crystal type arranged to be mounted on and adjusted from the front of a panel.

1,576,829—F. O. JOHNSON, of Chicago, Illinois. Filed August 23, 1924, issued March 16, 1926. Assigned to Reliance Die & Stamping Company.
ELECTROSTATIC CONDENSER of the variable type where the rotor plates are journaled in bushings carried in the end plates of a condenser frame and arranged to be so adjusted as to properly center the rotor plates between the stationary plates.

1,577,108—E. E. CLEMENT, of Washington, D. C. Filed January 21, 1925, issued March 16, 1926. Assigned to Edward F. Colladay.
TRUNKING SYSTEM OF RADIO DISTRIBUTION, where a telephone network is used for the broadcasting of signaling energy to a plurality of subscribers' stations.

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*Received by the Editor, May 17, 1926.

1,577,109—E. E. CLEMENT, of Washington, D. C. Filed January 31, 1925, issued March 16, 1926. Assigned to Edward F. Colladay.
RADIO BROADCAST DISTRIBUTING SYSTEM, where signaling energy is broadcast from a central station to subscribers and the energy properly amplified for serving the various subscriber circuits.

1,577,195—R. C. ROSE, of Osceola, Kansas. Filed October 10, 1925, issued March 16, 1926.
CONDENSER, of the stack type where end plates of glass are provided for securing the stack under pressure.

1,577,443—L. S. BRACH, East Orange, New Jersey. Filed July 21, 1925 issued March 23, 1926. Assigned to L. S. Brach Manufacturing Company.
RADIO RESISTOR COUPLER UNIT, consisting of a condenser and resistance within a casing with an identifying plate on the casing for representing the value of the coupling unit.

1,577,613—F. W. DUNMORE, of Washington, D. C. Filed February 4, 1925, issued March 23, 1926.
RADIO RECEIVING APPARATUS, in which the several tuning circuits of the apparatus are simultaneously controlled by operating condensers by means of cams.

1,577,719—W. H. T. HOLDEN, of Brooklyn, New York. Filed December 30, 1922, issued March 23, 1926. Assigned to American Telephone & Telegraph Company.
ELECTRICAL PROTECTIVE DEVICE, comprising a tube structure which may be connected in an antenna circuit for preventing destruction of signaling apparatus from high potential surges.

1,577,727—F. W. KARGE, of Chicago, Illinois. Filed April 20, 1925, issued March 23, 1926.
COMBINATION FIREPLACE AND CONTAINER FOR RADIO RECEIVING SETS, wherein the receiving set is mounted directly over the fireplace in the home.

1,577,748—D. R. LOVEJOY, of New York City. Filed August 14, 1924, issued March 23, 1926. Assigned to Lovejoy Development Corporation.
ELECTRICAL CONDENSER, where the plates are cylindrical and concentrically arranged one with respect to the other.

1,578,258—A. BLONDEL and M. TOULY, of Paris and St. Cloud, France. Filed May 18, 1921, issued March 30, 1926.
MEANS FOR GENERATING HIGH FREQUENCY CURRENTS by a plurality of electron tube circuits which are retroactively coupled for the production of oscillations.

1,578,288—C. W. HOUGH, of Boonville, New York. Filed September 27, 1922, issued March 30, 1926. Assigned to Wired Radio, Incorporated.
LAMP SOCKET ATTACHMENT DEVICE, by which signaling apparatus may be connected with the electric lighting line through condenser devices for capacitively coupling the receiving apparatus with the lighting line.

1,578,296—A. H. TAYLOR, of Washington, D. C. Filed October 2, 1925, issued March 30, 1926. Assigned to Wired Radio, Incorporated.
MULTI-FREQUENCY CRYSTAL CONTROLLED OSCILLATOR, in which a high frequency signal transmitting system is controlled by piezoelectric crystal devices.

1,578,513—J. H. HAMMOND, JR., of Gloucester, Massachusetts. Filed (Original), March 31, 1914. Reissue filed July 1, 1921, issued March 30, 1926.
SYSTEM AND METHOD OF PRODUCTION OF CONTINUOUS OSCILLATIONS, wherein an oscillator is coupled to an antenna system and the tuning device for varying the frequency of the oscillations directly inserted in the antenna circuit.

1,578,551—C. SCHWARZ, of Charlottenburg, Germany. Filed October 31, 1921, issued March 30, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
RELAY ARRANGEMENT FOR CHANGING THE TUNING OF

RADIO APPARATUS, whereby the transmitting apparatus may be operated on any selected frequency.

1,578,735—H. F HUNTER and L. S. HANNOLD, of Swendensboro, New Jersey. Filed May 8, 1924, issued March 30, 1926.
RADIO WAVE RECEIVING DEVICE, in which a wave coil is used in the reception of radio signals and compactly arranged with the associated apparatus.

1,578,394—H. E. CARLSON, of Minneapolis, Minnesota. Filed May 8, 1924, issued March 30, 1926.
RADIO CABINET, in which the apparatus is compactly mounted within the area of the loop antenna provided in the set.

1,578,396—G. H. CLARK, of Brooklyn, New York. Filed April 26, 1921, issued March 30, 1926. Assigned to Radio Corporation of America.
RADIO SIGNALING SYSTEM, where the oscillations at the transmitting station are varied at an audible rate to permit receivers to respond to the transmitted signals without the employment of a local oscillator.

1,578,490—R. A. WEAGANT, of New York City. Filed April 30, 1920, issued March 30, 1926. Assigned to Radio Corporation of America.
APPARATUS FOR PREVENTING INTERFERENCE IN RADIO SIGNALING, wherein the transmitting station generates two radio frequency currents which must be incident upon the receiver for the production of a beat frequency in order that the transmitted signals may be received.

1,578,832—JOSEPH A. KLAUSE, of Philadelphia, Pennsylvania. Filed March 15, 1923, issued March 30, 1926.
CONDENSER construction, wherein a plurality of condenser units are compactly arranged in a group.

1,578,845—E. L. NELSON, of East Orange, New Jersey. Filed January 16, 1924, issued March 30, 1926. Assigned to Western Electric Company, Incorporated.
MODULATION INDICATING SYSTEM for determining the condition of modulation in a transmitting system.

1,579,117—K. H. KINGDON, of Schenectady, New York. Filed July 1, 1921, issued March 30, 1926. Assigned to General Electric Company.
ELECTRON DISCHARGE DEVICE operating upon the principle of ionization within a vessel with a plurality of electrodes geometrically arranged within the vessel and connected to external circuits.

1,579,156—J. H. SIEMAN, of Brooklyn, New York. Filed May 2, 1924, issued March 30, 1926.
ELECTRICAL CONTACT FOR TERMINALS OF VACUUM TUBES, wherein the pins of the electron tubes have coil springs thereon for establishing contact with the socket terminals.

1,579,168—C. E. VAWTER, of Philadelphia, Pennsylvania. Filed April 28, 1923, issued March 30, 1926. Assigned to Dubilier Condenser and Radio Corporation.
ELECTRIC CONDENSER, wherein pressure is secured upon a stack by a metallic casing which is deformed over the stack.

1,579,209—H. P. CLAUSEN, of Mamaroneck, New York. Filed November 21, 1923, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
VARIABLE CONDENSER, where the rotor plates may be locked in any selected position.

1,579,253—E. SINGER, of New York City. Filed May 21, 1923, issued April 6, 1926. Assigned to Western Electric Company.
RECEPTION OF SIGNALS for securing high selectivity by reducing the frequency of the incoming signals through a series of steps.

1,579,299—J. C. GABRIEL, of New York City. Filed February 1, 1924, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
TWO-WAY COMMUNICATION SYSTEM, in which a solenoid device

is provided for shifting over from transmitting to receiving positions in a radio telephone system.

1,579,482—J. J. JORGENSEN, of Balboa, Canal Zone, Panama. Filed March 19, 1925, issued April 6, 1926.
VARIABLE AIR CONDENSER, where the rotor plates are mounted in an insulated frame spared from the end plates of the condenser by means of conical-shaped insulating devices.

1,579,614—A. W. HORNING, of Chicago, Illinois. Filed March 5, 1925, issued April 6, 1926.
RADIO WIRING SET, where the lengths of leads in a radio set are determined from patterns previously made up in the form of a dummy.

1,579,669—E. A. SPERRY, of Brooklyn, New York. Filed March 12, 1920, (original); divisional filed August 21, 1922, issued April 6, 1926.
RADIO REPEATER SYSTEM for securing simultaneous movement of an indicator at both transmitting and receiving stations automatically.

1,579,894—H. C. SNOOK, of South Orange, New Jersey. Filed May 31, 1922, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
OSCILLATION GENERATOR, in which a tube having a divided space current path is arranged in an external circuit for setting up oscillations.

1,579,895—H. C. SNOOK, of South Orange, New Jersey. Filed June 8, 1922, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
OSCILLATION GENERATOR, where the space current is increased in an electron discharge tube and the intensity thereof controlled by means of s supplemental control electrode arranged adjacent the grid.

1,579,921—H. F. ELLIOTT and J. A. MILLER, of Palo Alto, California. Filed January 9, 1922, issued April 6, 1926. Assigned to Federal Telegraph Company.
MULTIPLE RADIO SYSTEM, where a plurality of arc transmitters may be operated in close proximity to each other without interference.

1,579,930—A. HADDOCK, of East Orange, New Jersey. Filed September 28, 1923, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
RADIO TRANSMITTER, in which a mechanical switching device is provided for changing the transmitting wavelength of the antenna.

1,579,935—R. A. HEISING, of East Orange, New Jersey. Filed August 17, 1920, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
RESONANCE INDICATOR for determining the frequency of the transmitting system at a broadcasting station.

1,580,057—G. H. LEWIS, of Elizabeth, New Jersey. Filed April 12, 1922, issued April 6, 1926.
ELECTRICAL CONDENSER AND METHOD OF MAKING AND ADJUSTING THE SAME, in which variation in the electrical capacity of condensers may be compensated by changing the area of a number of the plates.

1,580,088—R. M. SANDERS, of New York City. Filed September 2, 1925, issued April 6, 1926. Assigned to Edward R. Tolfree.
REMOTE CONTROL FOR RADIO SETS, wherein the conductors which deliver the audio frequency energy to a reproducer are also used for controlling a relay for putting on and off the filaments of the receiving sets.

1,580,173—J. L. SECOR, of Mountainville, New York. Filed February 2, 1924, issued April 13, 1926.
VARIABLE CONDENSER, where minute adjustment of capacity may be made by selecting the number of stator plates actively in the circuit.

1,580,261—C. V. LOGWOOD, of New York City. Filed July 12, 1919, issued April 13, 1926.
ELECTRICAL SIGNALING SYSTEM, wherein a pair of electron tubes

are connected in balanced relationship for controlling an oscillation system.

1,580,359—C. T. ALLCUTT, of Pittsburgh, Pennsylvania. Filed December 30, 1920, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO RECEIVING SYSTEM of the heterodyne type where the sensitivity of the receiver is increased by circuit connections between the local source and the receiving circuits.

1,580,409—E. E. CLEMENT, of Washington, D. C. Filed February 14, 1925, issued April 13, 1926. Assigned to Edward F. Colladay.
TRUNKING SYSTEM OF RADIO DISTRIBUTION for transmitting over a line wire system signaling current to a plurality of subscribers from a central station and supervising the operation of the receivers from a central point.

1,580,423—P. E. EDELMAN, of New York City. Filed June 5, 1922, issued April 13, 1926.
VARIABLE CONDENSER, wherein the rotor plates are locked together by means of a locking pin which passes through all of the plate members for securing the plate members in position.

1,580,446—J. SLEPIAN, of Wilkinsburg, Pennsylvania. Filed April 21, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
ELECTRON TUBE, including a cathode and an anode arranged in a vessel which is provided with a restricted portion for the passage of electrons between the cathode and anode through a small cross-sectional area.

1,580,477—J. SLEPIAN, of Wilkinsburg, Pennsylvania. Filed April 21, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
OSCILLATION GENERATOR SYSTEM, in which a pair of two electrode valves are arranged in balanced relationship with an external electrode adjacent one of the valves for controlling the generation of oscillations in the circuits thereof.

1,580,509—D. G. LITTLE, of Edgewood Park, Pennsylvania. Filed June 3, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
COMBINATION OF INDUCTANCES FOR RADIO, for use in radio receiving sets for allowing the tuning of the antenna circuit to be varied without changing the amount of feed-back voltage induced in the grid circuit by the current in the plate circuit.

1,580,536—B. ROSENBAUM, of Berlin, Germany. Filed August 26, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
OSCILLATION GENERATOR, in which a plurality of electron tubes are arranged in co-operative relationship for varying the potential of the control electrode in each tube in accordance with variations of current in the wing circuit of another tube.

1,580,538—C. SCHWARZ, of Charlottenburg, Germany. Filed October 31, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
CONNECTING ARRANGEMENT FOR HIGH-FREQUENCY TELEPHONY, wherein a calling device is provided at the receiving station and operated from the transmitting station by a control switch for operating the system for inter-communication

1,580,621—G. J. MAHIEU, of Rio de Janeiro, Brazil. Filed March 13, 1925, issued April 13, 1926.
VARIABLE CONDENSER, in which one side of the condenser is formed by a plurality of wedge-shaped plates arranged to be moved into or out of a set of correspondingly shaped plates.

1,580,850—R. M. OTIS and W. F. FUNK, of East Orange, New Jersey and Midland Beach, New York, respectively. Filed June 29, 1925, issued April 13, 1926. Assigned to Bell Telephone Laboratories, Incorporated.

ELECTRON-DISCHARGE DEVICE, of high power construction, wherein a central rod is provided within the tube structure for carrying a corono shield thereon.

1,850,855—R. B. PRINDLE, of Schenectady, New York. Filed April 9, 1925, issued April 13, 1926. Assigned to General Electric Company.
COOLING SYSTEM FOR ELECTRICAL DEVICES, particularly adapted for maintaining the anode of a high power electron tube at uniform temperature under conditions of electronic bombardment.

1,580,873—J. J. WELDON, of Pittsfield, Massachusetts. Filed June 7, 1924, issued April 13, 1926. Assigned to General Electric Company.
STATIC CONDENSER, where a plurality of condensers are each formed in a roll supported from a frame structure.

1,580,898—C. IZENSTARK, of Chicago, Illinois. Filed June 7, 1922, issued April 13, 1926.
CRYSTAL DETECTOR, where a swivel joint carried by a bracket member is provided for securing adjustment of the contact device with respect to the crystal.

1, 580,899—J. B. JOHNSON, of Elmhurst, New York. Filed June 30, 1921, issued April 13, 1926. Assigned to Western Electric Company.
APPARATUS FOR MODIFYING THE WAVE FORM OF ALTERNATING CURRENT, including a vacuum tube having electrodes to be bombarded, the electrodes being of unequal thermal capacity with a source of alternating current connected to the electrodes and circuits so arranged for rendering the energy delivered to one of the anodes greater than that delivered to the other.

1,581,085—J. H. HAMMOND, JR., of Gloucester, Massachusetts. Filed (original), May 13, 1920; renewed August 15, 1924, issued April 13, 1926.
TRANSMITTING AND RECEIVING SYSTEM, in which a selective form of receiving apparatus is employed with a tube having a plurality of sets of grid and plate electrodes with associated circuits regeneratively coupled together.

1,581,133—F. H. MACKENZIE, of Philadelphia, Pennsylvania. Filed February 15, 1924, issued April 20, 1926.
RADIOAERIAL in the form of a coiled spring which may be expended for increasing the effective length and hooked between any suitable supports.

1,581,161—A. S. BLATTERMANN, of Little Silver, New Jersey. Filed April 18, 1921, issued April 20, 1926.
MEANS FOR REDUCING INTERFERENCE AND OBTAINING where the transmitted energy is varied at an inaudible rate and a corresponding variation effected at a selected receiving station.

1,581,219—J. O. MAUBORGNE and GUY HILL, of Washington, D. C. Filed August 6, 1920, issued April 20, 1926.
WAVE METER, employing a wave coil as a resonator by which the energy is picked up from a local emitter and the frequency thereof determined.

1,581,264—R. HERZOG and LEO PUNGS, of Berlin and Charlottenburg, Germany, respectively. Filed August 2[illegible] 1921, issued April 20, 1926. Assigned to Lorenz Aktiengesellschaft.
RADIO SIGNALING SYSTEM having means for modulating a transmitting system for radiating only a single wave while maintaining the source of oscillations in stabilized condition.

1,581,296—J. W. SCHMIED, of West Orange, New Jersey. Filed August 26, 1922, issued April 20, 1926. Assigned to Western Electric Company, Incorporated.
MODULATING CARRIER WAVES, by which increased high frequency voltage is impressed upon the transmitting circuit without utilizing a correspondingly increased voltage of the space current supply source of the vacuum tube system which produces the waves to be transmitted.

1,581,356—C. LOFBERG, of Bogota, New Jersey. Filed December 16, 1924,

issued April 20, 1926. Assigned to Nelson Tool Company, Incorporated. RADIO CONDENSER, where the adjustable plates are arranged to slide with respect to the fixed plates under control of a rack and pinion mechanism.

1,581,520—P. SCHWERIN, of New York City. Filed March 17, 1921, issued April 30, 1926. Assigned to Western Electric Company, Incorporated. VACUUM TUBE of high power construction, wherein a central stem is provided with arms extending therefrom for supporting the several electrodes of the electron tube.

1,581,649—A. LOPPACKER, of Bloomfield, New Jersey. Filed February 6, 1922, issued April 20, 1926. Assigned one-half to himself and one-half to Frank J. Kent.
DOUBLE-FACED DETECTOR ELEMENT, where the crystal is carried in a metallic sheet covering only the side walls of the crystal.

1,581,701—A. H. TAYLOR, of Washington, D. C. Filed October 24, 1925, issued April 20, 1926. Assigned to Wired Radio, Incorporated.
PIEZO-ELECTRIC CRYSTAL CONTROL SYSTEM, for maintaining the frequency of a high frequency signal system constant.

1,581,992—R. WEBSTER, of Evanston, Illinois. Filed June 23, 1923, issued April 20, 1926. Assigned to Fansteel Products Company, Incorporated, or North Chicago, Illinois.
RADIO DETECTOR OR AMPLIFICATION VACUUM BULB, having means for eliminating end fractions of the gaseous contents of a vacuum tube which consist in the plate element constructed of tantalum which when placed in a magnetic field during the process of manufacture tends to absorb gases within the tube.

1,582,042—F. W. HENNESSY, of Providence, Rhode Island. Filed March 3, 1924, issued April 27, 1926.
RADIO APPARATUS, comprising a telephone and connecting cords with a tip member which includes a rectifier unit. The telephone and connecting cords may be used together as a radio audibility unit, the rectifier being connected in series with the telephone.

1,582,177—J. H. HAMMOND, JR., of Gloucester, Massachusetts. Filed (original), September 25, 1917, issued April 27, 1926.
SYSTEM OF RADIO TELEGRAPHY AND TELEPHONY, in which the transmitting circuit is provided with a saturable core with an alternator for producing pulsations in the transmitting circuit and means actuated in synchronism with the alternator for causing saturation of the core to impress amplitude variations upon the impulses.

1,582,194—B. TRIVUS, of Providence, Rhode Island. Filed April 12, 1925, issued April 27, 1926.
DETECTOR of the crystal type where a metallic contact is carried by a bracket member and is adjustable with respect to a rectified crystal.

1,582,270—H. C. SNOOK and J. B. JOHNSON, of South Orange, New Jersey, and Elmhurst, New York, respectively. Filed March 18, 1922, issued April 27, 1926. Assigned to Western Electric Company, Incorporated.
METHOD OF AND MEANS FOR GENERATING ELECTRIC OSCILLATIONS by means of a discharge tube having an abnormal space charge.

1,582,441—C. H. VOTEY, of Hartsdale, New Jersey. Filed September 14, 1923, issued April 27, 1926. Assigned to The Aeolian Company.
MEANS FOR HOUSING THE RECEIVING LOOPS IN RADIO-SET CABINETS, where the loop is mounted on the cabinet door in such manner that it may be adjustable into any plane for securing desired directive reception.

1,582,460—L. F. FULLER, of Palo Alto, California. Filed June 13, 1922, issued April 27, 1926. Assigned to Wireless Improvement Company.
SIGNALING SYSTEM, utilizing an arc transmitter where an auxiliary ionizing discharge is produced in or about the arc space and this ionized discharge interrupted at the end of each signaling impulse whereby the arc may be intermittently established in accordance with signals.

1,582,519—C. H. HULBERT and W. J. TIDEMAN, of Menominee, Michigan. Filed January 10, 1923, issued April 27, 1926. Assigned to Signal Electric Manufacturing Company.
VARIABLE CONDENSER, having a minimum number of movable parts where the parts are concentrically arranged, one being movable with respect to the other for semi-circular displacement.

1,582,555—E. R. STOEKLE, of Milwaukee, Wisconsin. Filed March 27, 1925, issued April 27, 1926.
DEVICE FOR CONTROLLING AND INDICATING THE TUNING OF RADIO INSTRUMENTS AND THE LIKE, where a plurality of condensers are arranged on the same shaft and each adjustable by means which indicate the relative position of the several rotors of the condensers.

1,582,695—B. ROSENBAUM, of Berlin, Germany. Filed September 2, 1921, issued April 27, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO COMMUNICATION SYSTEM for remotely and selectively connecting a plurality of receiving stations which may have time clock mechanism installed therein.

1,582,720—V. K. ZWORYKIN, of Kansas City, Missouri. Filed February 16, 1922, issued April 27, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
METHOD OF TREATING VACUUM TUBES. By subjecting the electrodes of the electron tube to the action of a high frequency magnetic field which tends to heat the electrodes for driving out occluded gases at the same time that a periodically reversing potential is applied to the control electrodes.

1,582,780—P. T. PLATT, of Norfolk Downs, Massachusetts. Filed April 6, 1925, issued April 27, 1926.
RADIO WAVE METER, including an oscillating electron tube circuit with a grid leak and grid condenser arranged to produce a grid choking action for breaking up the radio frequency oscillations into groups at an audible rate.

1,582,826—A. A. KENT, of Ardmore, Pa. Filed May 8, 1925, issued April 27, 1926.
PANEL CONDENSER for mounting within a radio receiver where the rotor and stator elements are supported from the panel structure of the receiving apparatus.

1,582,975—S. B. GARCELLANO, of Charleston, South Carolina. Filed November 7, 1924, issued May 4, 1926.
BREAK RELAY FOR RADIO RECEIVING-SENDING SETS for permitting intermittent transmission and reception without interference of the transmitting set upon the local receiver.

1,583,071—A. A. KENT, of Ardmore, Pennsylvania. Filed May 12, 1925, issued May 4, 1926.
PANEL CONDENSER for mounting with respect to the panel of a radio receiving apparatus cabinet where the stator plates are mounted on a bracket supported from the panel and adjustable with respect to the rotor plates.

1,583,123—L. M. E. CLAUSING, of Chicago, Illinois. Filed August 16, 1923, issued May 4, 1926.
SYSTEM FOR GENERATING RADIO FREQUENCY CURRENTS, by employing a plurality of tubes upon which are impressed low frequency alternating currents for deriving a high frequency oscillating current in the transmitting circuit.

1,583,306—W. W. NEVINS and R. L. WALKER, of College Park and Atlanta, Georgia, respectively. Filed October 7, 1924, issued May 4, 1926. Assigned to A. E. Hill Manufacturing Company.
ELECTROSTATIC CONDENSER, in which alternating conductive and insulated sheets of circular shape are stacked within a metallic container and clamped under pressure.

1,583,414—E. W. B. GILL and E. GREEN, of Oxford, and London, England,

respectively. Filed October 31, 1925, issued May 4, 1926.
VACUUM TUBE SHIELD for surrounding an electron tube and confining and serving to control the distribution of electrostatic field therein.

1,583,463—W. G. HOUSEKEEPER, of New York City. Filed July 13, 1920, issued May 4, 1926. Assigned to Western Electric Company, Incorporated.
ELECTRON DISCHARGE DEVICE, of high power construction in which a cooling system is provided for maintaining the temperature of the electrodes at a uniform condition.

1,583,471—A. A. KENT, of Ardmore, Pennsylvania. Filed May 12, 1925, issued May 4, 1926.
PANEL CONDENSER, wherein the rotor and stator elements of the condenser are supported in insulated relationship to a metallic panel of a radio receiving set.

1,583,499—P. M. SMITH and E. M. SQUAREY, of East Orange and South Orange, New Jersey, respectively. Filed April 28, 1924, issued May 4, 1926. Assigned to United States Tool Company, Incorporated.
ROTOR SYSTEM FOR CONDENSERS, where the rotor plates of a condenser are constructed on a single integral sheet of metal.

1,583,503—E. M. SQUAREY, F. KOCH and A. E. BORTON, of South Orange and East Orange, respectively. Filed April 28, 2924, issued May 4, 1926. Assigned to United States Tool Company, Incorporated.
CONDENSER PLATE SYSTEM, where the plates are formed from a single piece of sheet metal with the plates folded and joined by integral tangs at the edges thereof for facilitating the manufacture of the condensers.

1,583,634—T. E. WHITE, of Waterbury, Connecticut. Filed May 17, 1924, issued May 4, 1926.
VARIABLE CONDENSER where the adjustable plates are semicircular in shape and may be varied in relation to stationary plates of circular shape.

PROCEEDINGS OF
The Institute of Radio Engineers

Volume 14 AUGUST, 1926 Number 4

CONTENTS

GENERAL INFORMATION

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings and at the Sections in the several cities listed on the following page.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership.

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INSTITUTE ACTIVITIES

Elected and Transferred to Member Grade

Members elected and transferred at the June 2nd meeting of the Board of Direction. The report of the Admissions Committee for May was approved, authorizing the election or transfer to grade of Member of the following: Zeh Bouck, Axel G. Jensen, H. T. Friis, H. H. Beverage, O. G. Mauro, D. F. Whiting, I. S. Bobrovsky, H. H. Bouson, E. E. Freeman, L. S. Hawkins, Coke Flannigan, F. J. Kahn, P. H. Boucheron, R. S. Kruse, Harris J. Rogers.

Washington, D. C., Section

A meeting of the Washington Section was held in the Department of Commerce building at Washington on April 14th, 1926. A talk on "The Translation of Electro-Mechanical Movements Into Sound Vibrations," was given by Mr. M. C. Hopkins. Mr. Hopkins demonstrated with apparatus the possibility of reproducing the deep base notes sometimes lacking in radio reception.

The Section also held a regular meeting on May the 12th, at which a talk was given by Mr. George Clark on the subject "The Evolution of Radio."

Rochester, N. Y., Section

A meeting of the Rochester Section was held on April 21st, jointly with the Rochester Engineering Society. Seventy-five members and guests were present. A talk was given by Mr. Harry Sadenwater who described the Broadcasting Stations WGY, KOA, and KGO, also the fifty-kw. transmitter at Schenectady. A meeting was held on May 21st, a talk being delivered by Mr. L. C. F. Horle on the subject "New Developments in Radio." A paper was read also on the subject of "Design of Radio Amplifier Circuits," by Mr. K. Henderson.

San Francisco Section

The San Francisco Section held a meeting on May 20th in the auditorium of the Pacific Gas and Electric Company, San Francisco. Mr. C. W. Latimer gave a talk dealing with the High Power Trans-Oceanic System of the Radio Corporation of

America, illustrated with motion pictures and slides. Mr. R. E. Mathes gave a detailed explanation of the operation of the system of Photo-Radio Transmission employed by the Radio Corporation of America. The talk was illustrated by lantern slides. Fifty-two members were in attendance.

Philadelphia Section

A re-organization meeting was held by the members of the Philadelphia Section on May 21st. Very interesting talks were given by Stuart Ballantine, W. L. Sayre and David P. Gullette. A meeting was held on July 12th, at which 100 members were present. A paper, illustrated with slides was read by W. E. Holland, on the subject "A, B and C Power from Alternating Current Sources." The next meeting of the Section will be held about September 15th.

Proposed Section at Detroit

A preliminary meeting was held by Institute members in Detroit, Michigan, on May 22nd, twenty-seven being present. The purpose of the meeting was to consider the proposal to establish a Section at Detroit. Temporary officers were elected as follows: W. A. Pedersen, temporary chairman; E. H. Clark, temporary vice-chairman; W. R. Hoffman, temporary secretary-treasurer.

As soon as the plans are completed the Section will be placed on a permanent basis and will hold regular technical meetings. At the preliminary meeting thirty-four members were present.

Proposed Section at Hartford, Conn.

A meeting was held in Hartford, Connecticut, on May 26th, with the object of determining whether or not a Section of the Institute can be established and operated to advantage with headquarters at Hartford. Among those who attended the preliminary meeting were: Dr. W. G. Cady, Dr. K. S. Van Dycke, H. P. Maxim, R. B. Bourne, K. B. Warner, A. L. Budlong, A. A. Herbert, F. E. Handy, F. C. Beekley, C. B. Rodimon, J. M. Clayton, H. P. Westman, R. S. Kruse.

A second meeting was held at Scott Laboratory, Wesleyan University, Middletown, Connecticut, on June 22nd, at which Dr. Cady and Dr. Van Dycke discussed the theoretical and practical aspects of the Piezoelectric Crystal with special reference to radio applications.

Employment

At Institute headquarters occasional calls are received for radio engineers and technicians. The Institute does not maintain an employment bureau, but the headquarters staff will be glad to receive inquiries from employers concerning their staff needs. The technical experience of those looking for employment is a matter of regard at headquarters and such information can be given to employers when so authorized by applicants for employment.

Toronto Section

The Toronto Section held a meeting on May 5th at which a paper was read by Mr. D. Hepburn on the subject of "Resistance, Reactance and Inductance." The officers elected to serve during the coming year are: Honorary Chairman, Professor T. R. Roseburgh; Chairman, D. Hepburn; Vice-Chairman, George F. Eaton; Secretary, C. C. Meredith; Assistant Secretary, C. I. Soucy; Treasurer, A. L. Ainsworth.

The Canadian Section is planning having one or two summer outings, possibly at Niagara Falls, to which all members of the Institute in Ontario and Quebec, as well as Northern New York State will be invited to attend.

The Section proposes to hold meetings in a lecture room of the Electrical Engineering Department, University of Toronto, once a month, except June, July and August. The number of Institute members in Canada continues to increase satisfactorily.

Meetings and Papers Committee—Note on Illustrations

Illustrations should be deep black on white on separate sheets. Letters and numerals should be as large as practical. A wiring diagram and a curve or family of curves is usually quite plain when reduced to very small dimensions; however, the numerals and letters nust be relatively large to remain readable. More coordinate lines than necessary interfere with reduction. Sheets much larger than the curves are a waste of space.

The cost of cuts is proportional to their area and the cost of publications is proportional to the number of pages.

If the illustrations are not suitable, either the Institute must pay for reducing, or other illustrations must be requested from the author.

Illustrations that make the important points plain at a glance are very desirable because they save the time of the reader, but illustrations which do not add anything or embody confusing

non-essentials irritate the readers and add useless cost to the PROCEEDINGS.

Papers Available in Pamphlet Form

In addition to the list of papers available in pamphlet form given on page 277 of the June PROCEEDINGS, we have available in this form a paper on "Some Measurements of Short Wave Transmission," by R. A. Heising, J. C. Schelleng and G. C. Southworth, and a paper on "Combined Electromagnetic and Electro Static Coupling and Some Use of the Combination," by Edward H. Loftin and S. Young White. Copies of these papers may be procured free by members by writing to the Secretary.

New Members and Transfers

Associates transferred to the grade of Member at the meeting of the Board of Direction on June 30th were E. W. Dannals, H. O. Horneij, R. W. Augustine, W. P. Powers, S. W. Dean, A. E. Harper, G. E. Burghard and A. T. Murray. Direct election to Member grade: A. J. Carter, J .D. Relyea and H. A. Oleson.

No New York Meetings in July or August

There are no technical meetings held in New York in July or August, but the offices of the Institute are open continuously for the transaction of business.

Work of Standardization Committee

A meeting of Subcommittee No. 1 on Vacuum Tubes was held on May 28th in New York under the chairmanship of L. A. Hazeltine. A preliminary report describing methods of measurement of the important characteristics of vacuum tubes has been prepared by the Subcommittee and will be given further consideration at a meeting to be held within a few weeks.

COLLEGIATE TRAINING FOR THE RADIO ENGINEERING FIELD*

By

C. M. Jansky, Jr.

(Assistant Professor, Radio Engineering, University of Minnesota)

Every discovery in the field of abstract science is quickly followed by the adaptation of the new knowledge gained to the benefit of civilization. We have grown to expect this. The average individual today takes his radio receiving set and the programs it gives him very much for granted, just as he does his electric lights and his telephone. The engineer has developed

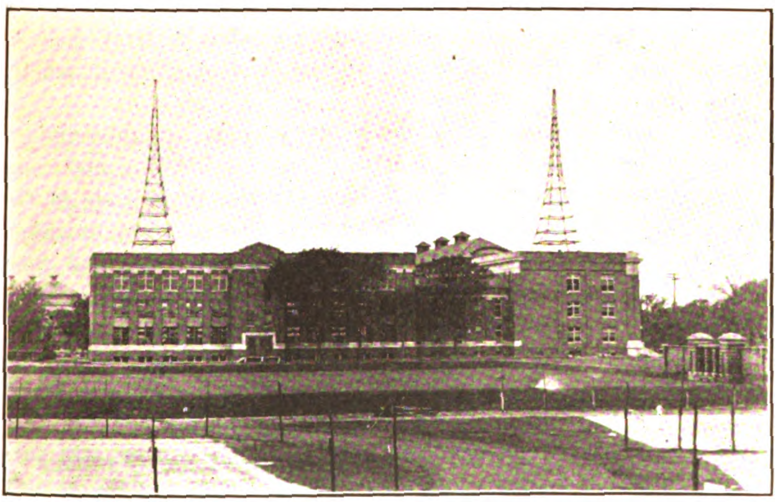

Figure 1—Electrical Engineering Building—University of Minnesota
(The Communication Laboratories occupy the third floor of this building)

these instruments of usefulness to a point where neither knowledge nor effort is required to operate them. As a result we must not be surprised to see a general lack of appreciation by the public of the intricacies of modern electrical apparatus and the work of those who have developed it.

*Received by the Editor May 5, 1926.
Presented before the Chicago Section, Institute of Radio Engineers, March 4, 1926, and at the New York meeting June 2, 1926.

Scientific development may be classified under two heads: that which increases our knowledge concerning fundamental physical phenomena and that which concerns itself with the development of apparatus and equipment the operation of which is based on these phenomena. Those studies which increase our knowledge concerning the nature and behavior of electricity belong to the field of physics. Those studies which have as their aim the development of apparatus and equipment utilizing fundamental electrical phenomena belong to the field of electrical engineering. An extreme physicist may be defined as one who, when he sees a practical application of his work, shies as far away from it as he can. An extreme "practical engineer" might be defined as one who, if he cannot see a practical application of a particular line of study, leaves it to others. As a matter of fact the most abstract theoretical physical investigations have often turned out to be of the greatest practical value, which proves that the distinction is not always an easy one to make. A striking illustration of this is the immense practical value of the theoretical investigations made over half a century ago by Clerk Maxwell in the field of electromagnetic radiation.

The field of electrical engineering may be roughly divided into two major divisions: electric power engineering and communication engineering. Until recently the magnitude of the power industry has overshadowed that of the communication industry. As a result, most collegiate courses in electrical engineering have been and in fact are today primarily courses designed to train men for the power field. By this I mean that in courses required of all students the fundamentals of electrical theory are taught by the aid of problems and illustrations which are almost entirely drawn from the power field. An analysis of the textbooks and laboratory manuals used in such courses will substantiate this statement. The fact that elective courses devoted entirely to the communication field are open to electrical students in addition to their required work does not alter the situation. A course of training which required of students a knowledge of the power field and leaves as optional a knowledge of the communication field will give the graduate a very lopsided view of electrical engineering in general. It is not difficult today to substantiate the statement that the communication industry is as important a factor in our civilization and offers as great opportunities to the graduate of electrical engineering as the power industry. Any discussion of the training of men for the field of

communication engineering which does not take account of this fact will fail of its purpose.

It is easy to say, and has often been said, that a course in electrical engineering should be based upon fundamentals. There is, however, often a wide difference of opinion as to what are and what are not fundamentals. Since physical knowledge is a basis for electrical engineering, and therefore radio engineering, it is obvious that a thorough course in physics should be an essential part of any training for the radio engineer. It is difficult to see how an understanding of complex radio phenomena can be obtained without the aid of a thorough knowledge of such physical concepts as force, mass, power, work, etc. Yet although courses in physics are an integral part in the training of all electrical engineers, I have yet to meet a group of senior students who did not have a hazy idea concerning these obvious fundamentals. More emphasis could well be placed on them.

A second obvious fundamental subject essential to any course in radio engineering is mathematics. Mathematics to the engineer is a tool which permits him to carry a number of variable quantities through transformations which enable him to check experiment or predict results. The engineer is at times inclined to look askance at the mathematician who studies his science for its own sake. Here again we must not forget that the most abstract investigations in mathematics may lead to the development of extremely practical tools which may be of great assistance to the graduate engineer. Examples of this are as plentiful in the field of pure mathematics as they are in the field of physics.

The importance of thorough training in physics and mathematics for engineers has been the subject of so much discussion by writers on education that the subject has become hackneyed. Yet no one will deny that many of our educational institutions continue to grind out graduates woefully deficient in this respect. The answer I presume is that to acquire a knowledge of these subjects, the student must cease to become a mere receptacle for information poured into him and must think for himself. It is much easier both from the standpoint of the teacher and the student to fill a student's head than it is to teach him to use it.

There is one other group of course incorporated in the curricula of most of our technical colleges, which I would designate as fundamental. This group includes those courses designed to increase the ability of the student to express himself either on paper or before an audience by word of mouth. The business of a lawyer requires that he analyze situations and present his

analysis to others with conviction. The engineer deals with highly technical and intricate developments. To leave presentation of those developments to the general public to others with less knowledge than himself, is to rob himself of the rewards which are justly his due. To command public attention, the engineer must be able to present his developments forcefully to those outside his profession. Mathematics is a useful tool, but its use is limited to those who understand it. The written and spoken word is the universal tool of civilized man.

Those of us in educational work are constantly charged with teaching too much application and not enough fundamentals. The cry of many in the industry is "give your students a knowledge of the fundamental physical sciences; leave the teaching of application to us. We can teach application better than you." Now if this be true, then why does not the industry turn a cold shoulder to electrical engineering graduates and draw its recruits entirely from those who have had training only in the field of abstract science, because, after all, electrical engineering is only applied physics. Yet even those who insist that the teacher should confine his attention to fundamentals, hire more engineers than they do physicists.

This leads to the question: what is the difference between a training in abstract mathematics and physics and a training in electrical engineering. The difference is that the student in electrical engineering has been taught to apply his physics to concrete engineering problems. It is entirely possible and even probable that the concrete problems used for illustrations will never be of any use to the engineer after he has graduated. This is not important. However, the ability to apply abstract science is as essential to the success of an electrical industry as is a knowledge of it. No one will, I think, argue that the teaching of the methods of applications should be left entirely to the industry itself. It it should, then courses in Electrical Engineering should be abolished.

The manufacturer who hires electrical graduates is very likely to analyze one of his recruits as he would the raw product he expects to use in his factory. For his purpose the graduate should have certain characteristics which would best fit him for work in his organization. Having told educators what characteristics he desires in his recruit engineers, why, he asks, does not the educational institution turn its attention to turning out a product which will have these characteristics. This might be possible were it not for the fact that the engineering student is not a piece

of material, but, on the contrary, is a human individual. During the entire period of his scholastic training the average student is trying to answer the very important question, "In just what kind of work and in what branch of engineering will I be happiest and most successful?"

No one can deny that the initial selection of a job made by the young graduate is of great importance. It is, therefore, the duty of the educator to give to the student as great an insight into the problems and opportunities of the various fields of electrical engineering as possible to the end that the graduates' initial choice may be a wise one. The presentation of engineering problems to the student which have been drawn from all branches of the industry, and which, in so far as possible, give the student some realization of what may lie beyond, is an admirable way of assisting the student in his efforts to select his life work wisely.

A serious criticism of an electrical engineering curricula which in its required courses draws all of its illustrative problems from the power field, is that graduates will select work in this field to the exclusion of all others. Men are loath to enter a line of work the problems and opportunities of which they know nothing. The communication industries have in the past found it very difficult to obtain engineering recruits for this reason. Men who have had a thorough training in courses drawing illustrations from the electric power field, may make as good communication engineers as anybody else, but in most instances the communication industry will never get them.

A properly-balanced course in electrical engineering in some good college or university undoubtedly offers the best training for the average prospective radio engineer. If the required work of this course does not give the student the fundamentals of electricity as applied to the communication problems, then the student should take elective courses designed to give him these fundamentals. The fact that these courses may be elective and may be titled "Telephony and Telegraphy" or "Radio Communication," does not necessarily mean that they are any more specialized than his required courses or that the teacher is concerned only with the application of fundamentals learned elsewhere. On the contrary, they are probably as fundamental and basic as any other courses he may be required to take, and may provide the only means of giving the material necessary to an understanding of the fundamentals of electricity as applied to the communication field. The theory of the vacuum tube, the theory of coupled circuits, the radiation of electro-magnetic waves, distortion of

wave form, the theory of circuits containing distributed capacitance, inductance, and resistance, and the meaning and measurements of transmission loss and gain are subjects which are not always sufficiently emphasized in average electrical engineering curricula of today for those who expect to become communication engineers.

One outstanding characteristic of the radio communication field is the number of new problems which are met at every turn.

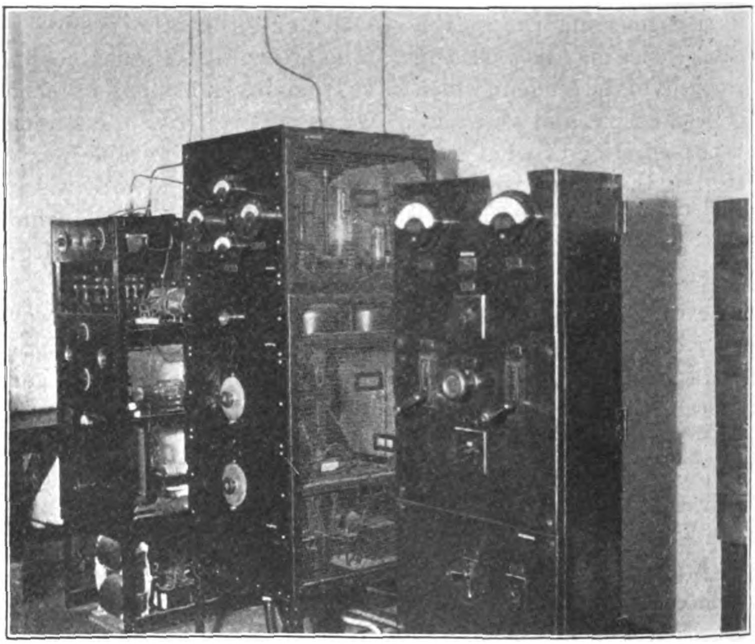

FIGURE 2—Short-wave Radio Telegraph Transmitter and Broadcast Transmitter—University of Minnesota Experimental Radio Station
(The short-wave transmitter was designed and built by students in the Department of Electrical Engineering)

Amateurs and broadcast listeners are continually trying new circuits and apparatus, most of them, it is true, with very little knowledge of what they are doing. The radio field offers an excellent opportunity for individual investigation on the part of the engineering student. Such work should not, however, be undertaken until the student has secured sufficient fundamental knowledge to derive some benefit from his experiments. In colleges having large registration it is difficult to give the student sufficient opportunity to exercise his own initiative. The laboratory work in courses containing a large registration must, of

necessity, be largely stereotyped. The student's experiments are outlined for him so that he knows what data to take, how to take it and what conclusions to draw. In an independent investigation the student is given a problem for which he must develop his own line of attack. He must decide upon what data he needs, what conclusions he can draw, and more important than anything else he should criticize his own results and judge their value.

During the past few years the writer has had a number of senior and post-graduate students working under him on individual investigations. The selection of a problem for the student is based on (1) his interest, (2) his ability to get somewhere with the problem, (3)the availability of equipment, and (4), the value of the results expected from the investigation.

In industrial work the last-mentioned point is all important. In educational work, except with candidates for higher degrees, it is of minor importance. The main object is to give the student training in the methods of independent investigation. The progress which I have seen students make in the development of their ability to analyze a problem, to search literature, and to take and draw conclusions from experimental data has been very gratifying and has convinced me of the value of scholastic training of this sort in spite of the amount of work it requires on the part of the teacher.

One of the peculiarities of radio communication is the fact that while man designs and builds the equipment necessary for the transmission and reception of radio waves he has no control and in fact very little knowledge of the transmission system he uses. Radio engineering today concerns itself largely with the design and construction of transmitting and receiving apparatus. Our knowledge of what goes on between transmitter and receiver and what conditions influence the strength and readability of signals at distant points is as yet very limited. This knowledge is largely of a statistical nature based on experience.

In view of the importance of the transmission medium in our communication system it would seem that some contact with it by the prospective radio engineer would at least be desirable. I know of no better method of studying transmitting and receiving conditions than by the actual transmission and reception of radio messages. Many a radio engineer became interested in his field as an amateur or commercial operator.

The American Radio Relay League deserves much credit for the stimulation it has given to amateur operation of radio stations and to interest in non-commercial experimental work. It would

seem that a closer alliance between this organization and our educational institutions would help to give students contact with actual radio communication and would in many other ways be mutually beneficial.

At the University of Minnesota Department of Electrical Engineering, we maintain an experimental radio station which serves a number of useful purposes. The station carries on extensive communication by short wave radio telegraphy with other experimental stations and amateur stations located all over the world. All construction and operation is carried on by a staff of student operators under faculty direction. This year the staff has eighteen members. The station is in operation normally about eighty hours each week. Actual transmission is carried on by men who have had extensive amateur or commercial operating experience. Other students not qualified operators are given the opportunity to design and construct equipment. Students may, if they choose, obtain a limited amount of credit towards graduation for work done in the radio station.

It is distinctly not the purpose of this work to train radio operators. Its principal object is to keep both students and faculty in touch with transmitting and receiving conditions as they actually exist. Incidentally, the experimental station yields much valuable information concerning transmitting conditions and also provides an excellent means for testing radio apparatus under conditions which stimulate those met in commercial practice.

Any student activity, the success of which requires respect for authority, systematized procedure, the ability to assume responsibility, co-operation with others, and yet permits an exercise of individual initiative cannot but help to train men to better meet the problems which will confront them when they enter modern industrial work. Radio station operation by students on a basis such as I have described provides such training.

The radio industry has enjoyed a remarkable growth during the past decade. It is not to be expected that such growth would take place without its problems. During the period when any radio manufacturer could sell equipment faster than he could make it regardless of quality it is small wonder that many have seen no necessity for services of well-trained engineers. However, conditions are changing rapidly. The public is already beginning to discriminate in favor of those manufacturers whose apparatus has been designed and constructed under the supervision of competent engineers. This discrimination on the part

of the public will do much to stimulate development and improvement. It will also bring about greater rewards to those who have sacrificed time and effort necessary to secure an adequate training in what is the youngest as well as one of the most technical of the electrical sciences.

DISCUSSION
ON "COLLEGIATE TRAINING FOR THE RADIO ENGINEERING FIELD," BY C. M. JANSKY

J. H. Dellinger: I would like to add one point to the very excellent ones brought out in Professor Jansky's paper, and it is a point which it was impossible for him to make. My added point is that we give too little credit to our educators. The honor and credit for the achievement in radio should be divided between the men who make the advances and the teachers who have trained them. Professors, and instructors generally, seldom get their due, and this is an excellent occasion to draw attention to that seriously neglected fact.

The common attitude toward educators and educational courses is one of broad criticism rather than praise. We have an effective offset to this critical attitude in papers like this one of Professor Jansky's which reveal how the educator is thoroughly alive to the problems before him and is capable of giving them as keen and thorough an analysis as any engineer gives an engineering problem. Professor Jansky has set forth a number of important ideas for our consideration and I would like to emphasize the ones which appear to me of particular importance. They are five in number.

First, he points out that in most electrical engineering courses "the fundamentals of electrical theory are taught by the aid of problems and illustrations which are almost entirely drawn from the power field." It is certainly true that the characteristic phenomena of electrical communication give just as valuable a province for instruction as those of electric power. This will unquestionably be given increasing recognition.

Second, it is pointed out as obvious that training in physics is an essential part of the radio engineer's education. While this is often stated and is indeed obvious, it cannot be given too much emphasis. This is proved by Professor Jansky's admission that "I have yet to meet a group of senior students who did not have a hazy idea concerning" the fundamental physical concepts. My own observation of the preparation and technical equipment of radio engineers gives strong emphasis to the need

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... training in fundamental physics. I have ... thankful that the gentleman who taught me ... illusions as to ability of students to grasp the ... came to know some of his philosophy of teaching, and ... that his experience had led him to the conclusion that if ... get even one physical principle thoroughly into the heads of his students so that they really knew it and used it, he felt that the year's teaching work was successful. Fortunately, a principle on which he concentrated was simple harmonic motion. Any student who got through his course without grasping the principle that in simple harmonic emission the force is proportional to the displacement probably was hopeless as far as learning physics was concerned. I believe it is fair to add that when a man has learned this particular principle he has secured a substantial part of the stock in trade of a well trained radio engineer.

Third, it is suggested that courses in expression are of fundamental importance. This point is seldom mentioned or realized. I believe it is of enormous importance, second only to the need of training in physics, that an engineer should be trained in the arts of expressing himself, either in writing or in speaking to an audience. Obviously few engineers spend much of their time in either writing or public speaking; nevertheless, all must do a certain amount of it, and shortcomings in a man's ability in expression all too often weigh heavily against and neutralize ability in his technical work.

Fourth, it is neatly demonstrated that the student of radio engineering must have technical training in his chosen field through the application of his physics and other fundamental work to concrete problems of radio engineering. The argument given on this disposes of the contention frequently made that the teaching of methods of application should be left entirely to a man's experience in the industry after graduation.

Fifth, and finally, we are reminded that students cannot be trained to fit a particular model as a piece of material would be fashioned into an instrument, because of the fact that the student is first of all a human individual. This again disposes of some criticisms leveled against educational institutions. The manufacturer would like to have recruits for the industry with a definite kind of preparation which could be prescribed as the result of analysis of the particular work the man is to do. That this is not in general possible hinges on the fact that by far the great majority of the students are not certain during their college

course as to what vocation they will pursue or for what branch of engineering they are fitted. The teacher cannot subordinate the human problem involved to the less important task of creating a mere standardized unit of work.

Of the various points brought out in Professor Jansky's paper, by far the most important is the emphasis on the need of fundamental training. The details of radio engineering or any other branch of engineering are ephemeral, and they have their roots in physical principles. To learn the principles of physics and how to apply them to understand, to modify, and eventually to create engineering processes is much more difficult and far more important to the student than the practical engineering. I would venture to defend the thesis that the responsibility of the position attainable by a man is proportional to his grounding in the fundamentals of his subject. I do not mean at all that opportunity and other circumstances necessarily always bring a man to this position, and, on the other hand, his grounding in fundamentals must be actual and does not mean that he has merely been exposed to knowledge of fundamentals through taking certain courses. There is no way to learn the fundamental facts of a profession and to understand the processes which are vital except by hard work. I believe it to be true that not only the responsibility of the position open to a man but the contribution he can make to his field of work and the satisfaction he can get out of life, are proportional to his grounding in the fundamentals of his vocation.

Alfred N. Goldsmith: It is unquestionably one of the functions of universities to train specialists in professional branches, such as radio engineering. There is not, however, a widespread knowledge of the real qualifications of a radio engineer. The following definition may be proposed: "A radio engineer is an electrical engineer who has first specialized in communication engineering, and then sub-specialized in radio communication." Guided by this definition, it is clear that the fundamental training of a radio engineer is that of an electrical engineer. His first specialization should be in the field of alternating current phenomena at high frequencies and the characteristics which are displayed to such currents by networks and systems having concentrated or distributed electrical constants. If electric courses on advanced transformer design and, under the division of physics, on acoustics are available, the student will do well to choose these.

The sub-specialization in radio engineering will deal with the

theory and construction of the specialized circuits used in radio transmitting and receiving apparatus, together with a careful study of that universal device, the triode, or three-electrode tube. A great deal of emphasis should be placed on the laboratory side of the work because the field is new and rapidly changing, and only those who have had direct contact with actual equipment will be spared the continual mortification of embarrassing mistakes based upon too slavish a reliance on narrow theoretical considerations.

There are today relatively few universities giving training in the field of radio engineering which, perhaps, is just as well, since the absorption of trained men in the radio engineering field (despite public interest in this field) is rather limited. It may be added that a radio engineer, on graduation from the university, is qualified to begin his career in a somewhat humble capacity, since he must get experience in the test, design, and manufacturing divisions of a commercial organization of some scope before he can be depended upon to meet the requirements of this fairly difficult profession. However, it is a most interesting field and the workers in it feel that they are in the van of progress.

Arthur F. Rose: Professor Jansky's paper is of considerable interest to all of us who are engaged in communication work, although it applies particularly to the radio engineering field which Professor Jansky has emphasized. His analysis of the time-worn policy of industry urging "emphasis of fundamentals in the engineering curriculum" is a very valuable contribution and will aid in bringing together the viewpoints of those in the field and the educators. The question of what constitutes fundamentals has been the subject of many discussions, all of which result in the conclusions that the same fundamentals form the basis for both communication engineering and power engineering. The difference between the two is only the question of the frequencies and the amount of power involved. In the power field a single frequency and large quantities of power are studied, while in the communication field minute quantities of power but a very large range of frequencies are involved.

The radio engineer or the communication engineer in his design work must study the action of his circuits throughout the frequency range of voice transmission. For instance, the sharply tuned circuits of radio sets react very differently at the different frequencies and may introduce appreciable amounts of distortion if not considered carefully from this standpoint. Therefore, the fundamental conceptions which the student obtains in his

early studies should not be restricted to single frequency reactions.

Again in connection with the question of teaching engineering applications in the colleges, Professor Jansky has emphasized the importance of teaching the student how to apply his fundamental knowledge to specific problems. This is, of course, the aim of all education, for as Ruskin says, "All knowledge is lost which ends in knowing, for every truth we know is a candle given us to work by." In some cases, however, the tendency has been to attempt to make the student a finished radio engineer after having taken a course on radio telephony. This, of course, is a mistake, as the text books and problems used in the courses must necessarily lag considerably behind the practical application of the art in the field. In radio engineering particularly, the art is changing so rapidly that it appears futile to attempt to teach detailed application, but better to concentrate on the more fundamental aspects and by practice acquire skill in approaching new problems.

USES AND POSSIBILITIES OF PIEZOELECTRIC OSCILLATORS*

By

August Hund

(Physicist, Bureau of Standards)

Certain crystals [1] which lack symmetry exhibit electrical charges in particular regions when subjected to stress or when heated or cooled. When the electrical charges are due to stress the effect is called piezoelectric, and, when due to heat, pyroelectric. All piezoelectric substances are pyroelectric, and it is doubtful if any pyroelectric effect would be obtained if stresses were eliminated. The effect of stress was discovered by P. and J. Curie.[2]

Though Rochelle salt has the greatest piezoelectric effect, and quartz a comparatively small one, the latter substance, on account of its mechanical properties, is more suitable for the uses and applications here described. Pioneer work in the practical applications of the piezoelectric effect has been described[3] by several experimenters. Prof. Cady and Prof. Pierce have been responsible for most of the applications of value in radio communication.

Quartz has a crystalline structure, as shown in Figure 1, OX being the optic axis. A plate cut out with its surface parallel to the OX axis and either of the other two principal axes, OY or OZ, shows piezoelectric effects which are very pronounced.

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[1] Rochelle salt, tourmaline, silicate of zinc, cane sugar, quartz, boracite, etc.

[2] Comptes Rendus, vol. 91, pp. 294 and 383, 1880. Voigt, "Lehrbuch der Kristallphysik," Leipsig, 1910; Graetz, "Handbuch der Elektrizitat und des Magnetismus," vol. 1, Leipzig, 1914. For similar observations consult Gehlers Physikalische Woerterb. Bd. 3, p. 255, 827. W. C. Roentgen, Weid. Ann. Bd. 18, p. 534, Bd. 19, p. 523, 1883. M. G. Lippman, Ann. d. Chemie (5), T. 24, p. 45, 1881. W. Thomson, Phil. Mag., vol. 36, p. 331, 1893.

[3] A. M. Nicolson, Proc. A. I. E. E., vol. 38, p. 1315, 1919; W. G. Cady, Proceedings of The Institute of Radio Engineers, vol. 10, p. 83, 1922; and G. W. Pierce, Proc. American Academy of Arts and Sciences, vol. 59, No. 4, p. 81, 1923.

Axes AB, CD, and EF are known as the piezoelectric axes. Piezoelectric effects are observed when the plate is placed between two metal sheets. The planes of the sheets are then perpendicular to one of the piezoelectric axes and parallel to the optic axis of the crystal. If the quartz plate is compressed, opposite charges will be induced in the two conducting sheets. Elongation reverses the polarity. Hence if the circuit is closed by a conductor connecting the two metal sheets, and the plate is subjected to alternating mechanical impulses, it generates corresponding alternating electric currents. An alternating e.m.f. impressed across the piezoelectric plate will also cause a similar mechanical vibration in it. This is true even if the metal sheets are not quite touching the respective faces of the plate.

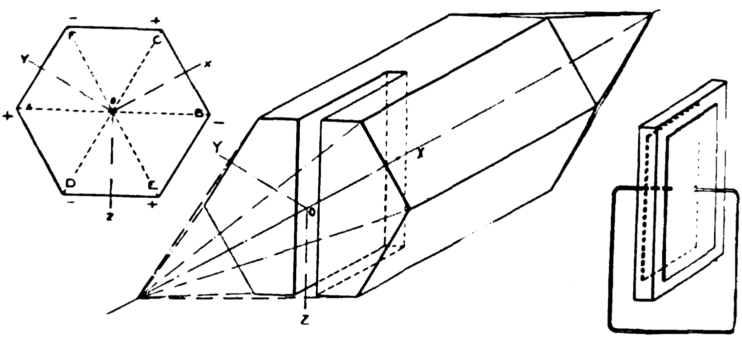

FIGURE 1—Quartz Crystal and Piezoelectric Plate

Piezoelectric Oscillator—From the foregoing it is evident that a plate of quartz can be used for converting mechanical vibrations into electrical oscillations and vice versa. The effects are greatest when the electrical oscillation is adjusted to resonance with a possible natural mechanical vibration of the piezoelectric plate. Using an electron tube circuit it is possible to have the piezoelectric plate control the oscillations which are set up. Such an arrangement is shown in Figure 2 where a quartz plate can be inserted either between the grid and the filament or between the grid and the plate.

The action of the circuit is as follows: Upon closing the circuit or moving certain portions of it, a transient current is started in it whose decay assumes a frequency which is due to a possible mechanical vibration of the piezoelectric plate. Normally such an oscillation would die out before being noticed. If, however, an inductance, L, of proper magnitude is inserted in the

plate circuit, it will, by means of the feedback[4] through the tube itself, render the circuit regenerative, that is, produce the equivalent of a negative resistance between the grid and the filament, and sustain the oscillations due to the piezoelectric element. Whenever this happens, the plate current measured by a d. c. milliameter drops to a minimum value. The output can be increased by using a variable condenser, C, in parallel with the inductance, L, of the plate circuit. With the quartz plate connected between the filament and the grid, the condenser is set at its minimum position and its capacity is gradually increased. For a certain setting, the oscillations begin to build up and while increasing C, the plate current will decrease until the oscillations stop altogether when close to the resonance setting of the C-L circuit. For the quartz plate connected to the anode and the

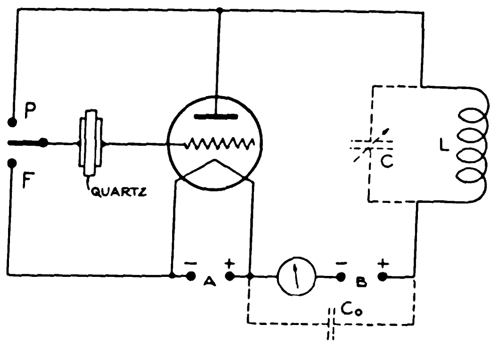

FIGURE 2—Circuit Connections for a Piezoelectric Oscillator

grid, the capacity, C, has to be gradually decreased from the maximum setting in order to start the oscillations. The building up of the oscillations takes place normally in a fraction of a second, but in some cases it may require several seconds, and it is therefore necessary to change C slowly. The slow building-up of the oscillations may be due to either a poor piece of quartz, incorrect value of the inductance L, or the lack of necessary freedom of the quartz plate. When using the quartz plate as an oscillator it is necessary for it to be free to move, while for use as a resonator the conductive layers can

[4] If the piezoelectric element is inserted between the filament and the grid the plate to grid capacity acts as the agency for the feedback of the plate actions into the grid branch. The filament to grid capacity provides the feedback, if the quartz plate is connected between the grid and the anode.

even be pasted on the piezoelectric plate or clamped against it without disturbing the operation.

Cutting of Quartz Plates Suitable for Oscillator Work.—Figure 3 shows a large piece of quartz which rests on a surface perpendicular to the optic axis along which no "direct" electrical effect is possible. Figure 4 shows another crystal of quartz likewise resting on a plane perpendicular to the optic axis. The lines indicate where a plate is to be cut out. Cuts of this type give a maximum piezoelectric effect with a small temperature coefficient which is either positive or negative. Although there are

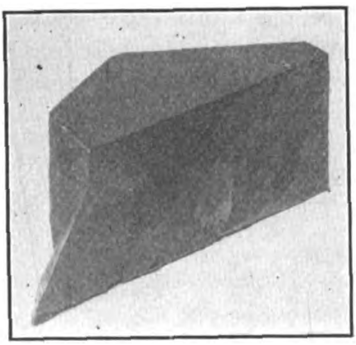

FIGURE 3—Piece of Quartz Resting on a Plane Perpendicular to the Optic Axis and Cut Along an Axis Such as OX, OY or OZ.

FIGURE 4—A Suitable Cut for Obtaining a Plate for Piezo Oscillators

cuts for which the temperature coefficient is zero it has been found more practical to cut as closely as possible along OX, OY or OZ directions (Figure 1) since then three well-defined natural vibrations occur. Figure 5 shows a quartz plate removed from the original crystal while Figure 6 shows several plates cut out from the same block. From such slices either rectangular plates are cut out as indicated on one of the slices or circular plates are cut out by means of a revolving brass tube. The latter shape can be secured more quickly since there are only two faces which need to be made parallel. There are several methods of cutting out slices from the natural crystal. One method is to use a plate of galvanized iron or copper which revolves against the crystal. To this is fed No. 150 carborundum powder mixed with about the same amount (by volume) of water. The work can be done somewhat faster by using a plate of copper whose circumference is finely ribbed and charged with diamond dust, using a steady

flow of kerosene against the cutting edge. The faces are ground parallel first by means of No. 60 carborundum and water and then with No. 150 carborundum and water. The finishing is done by means of No. 140 emery powder mixed with water, then No. 302 emery and No. 303 emery in water solution. Most

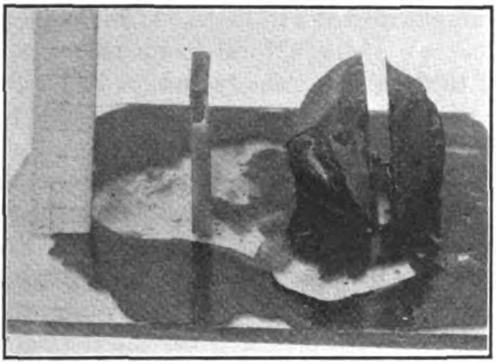

FIGURE 5—Quartz Plate Cut from the Natural Crystal

of the piezoelectric plates at the Bureau of Standards are polished to transparency by means of rouge and the edges somewhat bevelled. A polished plate sometimes has the tendency to chip

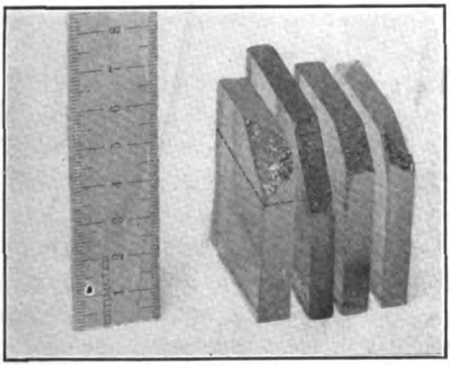

FIGURE 6—Several Piezoelectric Plates Cut from a Quartz Crystal

off near the edges. However, when the two main faces (parallel to the respective conducting layers) are polished, oscillations start more easily and such plates are usually more desirable. The breaking off of the small pieces may be due either to excessive mechanical vibrations in the plate or more probably to strains

left near the polished surface, as in the case of Prince Rupert drops.

Important Natural Mechanical Vibrations of Quartz Plates.—When quartz plates are cut out as described above and indicated in Figures 1, 4 and 5, it will be found that in general three fundamental modes of natural oscillations are possible. Several of the many samples tested are described in Table I, from which it is seen that two of the natural frequencies are close together with respect to the third. The reason for this is that the thickness of the plates is small in comparison with the other two dimensions.

When rectangular plates are cut not along planes parallel with either OX, OY, or OZ (Figure 1) but along planes of zero temperature coefficient of frequency or planes closer to directions OA, OD, or OE, either three or more natural mechanical vibrations occur and with frequencies which are not always in agreement with those expected when the normal cuts are employed. For example, a rectangular plate $24.94 \times 19.29 \times 3.03$ mm. gave $f_1 = 105$; $f_2 = 612$, and $f_3 = 924$ kc., that is, two higher frequencies, f_2 and f_3 respectively, in comparison to the third frequency f_1. A normal cut would have given two low frequencies and a high one. In another case four natural frequencies were obtained, the plate having the dimensions $24.775 \times 19.92 \times 3.04$ mm., that is, almost the identical shape as in the first case. These frequencies were $f_1 = 105.6$; $f_2 = 606.5$; $f_3 = 819.5$ and $f_4 = 932.5$ kc.

Using normal cuts as shown in Figure 1, it can be said that three fundamental natural frequencies are possible, irrespective of whether the cut is bounded by a rectangle, square, ellipse or circle, as long as the thickness is small, but not too small, in comparison with the other dimensions. If a thickness is used which is comparable to the other dimensions such as in a cube, it would take a strong electric field to start the oscillations and there would be little gain since the frequencies would be close together. In the same way when the shortest dimension becomes small, less than about 2 mm., special measures have to be employed to start the highest frequency.

In all cases, irrespective of shape, the fundamental vibration due to the thickness can be estimated with a good degree of approximation from the expression

$$f_3 = \frac{2870}{t} \tag{1}$$

when f is expressed in kilocycles per second (kc.) and the thickness t measured in mm. It is therefore seen that the product of the frequency and the thickness is a constant

$$K_3 = f_3 \cdot t = 2870 \tag{2}$$

This is shown by the data of Table I and II.

Data on circular plates used as piezo oscillators, f_1 is the lowest f_2 the medium, and f_3 the highest natural frequency of the quartz plate.

Since for oscillator work the surfaces of the piezoelectric plate are free, it can be assumed that a fundamental vibration has its node at the center of the plate and consequently the thickness is equal to one-half wave length. If v_3 denotes the velocity of propagation along the thickness t, that is, along the electrostatic lines across the plate and λ_3, the wave length, we have

$$v_3 = \lambda_3 f_3 = 2\,t f_3 = 2\,K_3 \tag{3}$$

Hence twice the value of the constant K_3 gives the velocity of propagation, 574×10^3 cm./sec. This result agrees within about 5% with a value obtained from a theoretical formula.[5] This agreement would probably be much better if the appropriate modulus of elasticity were used. The other frequencies which are lower and due to larger dimensions can not be calculated by formula (1). However, for circular plates

$$f_1 = \frac{2715}{d} \tag{4}$$

$$f_2 = \frac{3830}{d} \tag{5}$$

where d is the diameter of the plate in millimeters and the respective frequencies are again expressed in kilocycles. The characteristic constants for these two oscillations are then

$$K_1 = f_1\, d = 2715 \tag{6}$$

and

$$K_2 = f_2\, d = 3830 \tag{7}$$

and the respective velocities of propagation along the diameters are:

$$v_1 = 2\,K_1 = 543 \times 10^3 \text{ cm./sec.} \tag{8}$$

$$v_2 = 2\,K_2 = 766 \times 10^3 \text{ cm./sec.} \tag{9}$$

using similar assumptions as for v_1.

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[5] $$v_3 = \sqrt{\frac{\textit{modulus of elasticity}}{\textit{density}}} = \sqrt{\frac{785 \times 10^{11}\, dynes/cm.^2}{2.654\; gn/cc}}$$
$$= 540 \times 10^3\; cm/cc$$

TABLE I

DATA ON SEVERAL QUARTZ PLATES USED IN PIEZO OSCILLATORS

CIRCULAR PLATES.

Quartz Plate	Shape	Dimensions in mm.				Natural Fundamental Frequencies in kilo: cycles per second			Corresponding Wave lengths in meters							
		t	d	a	b	f_1	f_2	f_3	λ_1	λ_2	λ_3	f_3t	f_1a	f_2b	f_1d	f_2d
A	Circular plate	6.307	36.15			75.05	105.91	454.2	3995	2831	659.8	2871			2715	3815
B	Circular plate	4.782	39.17			69.36	97.625	600	4354	3070	499.5	2874			2700	3827
C	Circular plate	6.0	57.97			46.80	66.27	475.25	6405	4523	631	2854			2715	3841
D	Circular plate	5.78	49.3			55.115	77.82	492.8	5445	3860	608.5	2852			2717	3831
E	Circular plate	4.87	49.27			55.23	77.76	583.6	5425	3855	505	2893			2727	3831
F	Circular plate	6.075	49.3			55.01	77.715	470	5445	3860	638	2857			2717	3831
G	Circular plate	3.4325	49.58			54.88	77.375	843.7	5461	3880	355.2	2899			3725	3831
H	Circular plate	3.4975	58.38			46.5	65.675	822	6445	4560	364.7	2879			2717	3836
I	Circular plate	4.277	39.37			68.5	97	670	4376	3090	447.5	2868			2700	3822
J	Circular plate	8.805	21.84			124.8	175.5	326.75	2401	1708	917.5	2882			2727	3836
K	Circular plate	8.28	29.2			93.4	131.8	346.25	3210	2273	866	2876			2727	3856
						Rectangular Plates										
L	Rectangular plate	3.12		31.855	25.155	79.925	105.41	924.57	3752	2843	324.2	2887	2549	2655		
M	Rectangular plate	4.909		39.005	30.295	70.69	102.42	587	4240	2928	510.5	2886	2759	3099		
N	Rectangular plate	7.177		42.08	39.62	66.05	85.43	404	4538	3508	742	2901	2786	3390		
O	Rectangular plate	3.264		36.82	25.2	80.485	106.67	873.5	3725	2810	343.4	2854	2967	2691		
P	Rectangular plate	7.59		44	35	64.6	83.4	382.8	4640	3595	783.5	2907	2846	2921		
Q	Rectangular plate	6.83		48.5	37.5	59	78.8	417.4	5080	3805	718	2855	2866	2956		
R	Rectangular plate	5.04		39	30	70.7	102.2	569.5	4240	2932	527	2871	2762	3067		

f_1 is the lowest, f_2 the medium, and f_3 the highest natural frequency of the piezo oscillators. t is the thickness of the rectangular plate, d the diameter of the circular plates, a and b are the length and breadth of the rectangular plates.

The optic axis is along a line which is parallel to the circular planes of the plate and so one diameter is parallel with the optic axis. Along a diameter perpendicular to the optic axis the modulus of elasticity is, as given in footnote 5, 7.85×10^{11} dynes/cm.^{2} and with the density value given in that formula confirms exactly the velocity, v_1, of equation (8). The value, v_2, is high and even if it is assumed that the vibration occurs along the direction of the optic axis for which the modulus would be 10.3×10^{11} dynes/cm.^{2} the theoretical velocity is only 623×10^3 cm./sec., which is about 22 percent low. The mechanism for this oscillation is

TABLE II

DATA ON CIRCULAR PLATES USED AS PIEZO OSCILLATOR

Quartz Plate	Natural Fundamental Frequencies in Kilocycles per second			Corresponding Wave lengths in meters			$f_1.d$	$f_2.d$	$f_3.t$
	f_1	f_2	f_3	λ_1	λ_2	λ_3			
A_1	74.95	105.5	452.5	4000	2842	663	2710	3814	2856
A_2	75.05	105.91	454.2	3995	2831	659.8	2713	3829	2865
A_3	74.9	105.15	454.25	4003	2853	660	2707	3800	2868
A_4	75.4	106.0	457.0	3976	2828	656	2726	3830	2873
A_5	74.75	105.35	454.5	4011	2847	659.5	2700	3810	2869
A_6	75.0	105.75	454.5	3997	2835	659.5	2710	3828	2869
A_7	75.1	106.25	453.75	3991	2822	661	2713	3840	2861
A_8	74.8	105.5	457.25	4007	2842	655.5	2703	3814	2887
A_9	75.25	106.5	453.25	3984	2815	661.5	2720	3850	2860
A_{10}	74.75	106.0	454.25	4011	2828	660	2700	3830	2868
A_{11}	74.8	105.95	453.25	4007	2829	661.5	2703	3830	2861
A_{12}	74.95	105.55	454.25	4000	2840	660	2710	3819	2868
A_{13}	74.7	105.55	454.5	4013	2840	659.5	2700	3819	2869
A_{14}	74.75	106.1	454.5	4011	2827	659.5	2700	3835	2869
A_{15}	75.15	106.0	456.0	3989	2828	657	2716	3830	2869
A_{16}	75.05	105.75	454.5	3995	2835	659.5	2713	3825	2860
A_{17}	74.65	105.15	453.75	4016	2853	661	2699	3800	2860
A_{18}	75.1	106.1	453.25	3991	2827	661.5	2714	3836	2860
A_{19}	74.9	105.35	452.5	4003	2847	663	2707	3810	2856

(Circular Quartz plates all of the same size, diameter = 36.15 mm. and thickness = 6.31 mm. cut from different pieces of quartz as indicated in Figure 1.)

probably more complicated than the other two. Nevertheless this in no way gives any practical difficulties since equation (5) can be used to a fair degree of approximation even though a better explanation cannot be given at the present time.

According to Table I and many other data, it is more difficult to give good approximation formulas for the two low frequencies, f_1 and f_2, respectively, of rectangular plates since some values deviate too much from the average value. The average value of the lowest frequency gives a characteristic constant of about $K_1 = 2785$ and for the medium frequency $K_2 = 2945$. The corresponding velocity values, $v_1 = 2\ K_1$, and $v_2 = 2\ K_2$, are reasonable. It is interesting to note that their average value gives about the value for the constant K_3. From these observations it looks as though the three characteristic vibrations occur along the three main dimensions. This appears to contradict the theory

of piezoelectricity, at least at first sight, since one dimension is parallel to the optic axis along which no piezoelectric effect is possible. But since a contraction across a set of small faces perpendicular to the optic axis produces an expansion along this axis and vice versa, there will be a disarrangement of the molecules. The effect of this probably produces the third vibration.

Another explanation would be that the piezoelectric plate acts like a coupled circuit which produces two frequencies, one which is somewhat lower and another which is somewhat higher than the expected frequency. The degree of coupling is dependent on the relative magnitude of the three main axis.

A third explanation makes use of the fact that the vibration parallel to the two conducting layers may be due to both a transverse and a longitudinal wave motion which have different velocities of propagation and so produce two waves of different frequencies.

Experience indicates that it is best to use circular plates. It is essential that the faces be exactly parallel since otherwise the frequency spectrum of the highest frequency may give several values or not appear at all. It happens sometimes that a plate will not oscillate at all, although the faces appear to be parallel. A little grinding which would hardly be noticed with a micrometer brings in the oscillation. This is probably due to the fact that a certain stiffness exists so as to annul the effect. Sometimes after grinding, the oscillation disappears again and further grinding starts another higher oscillation and so on, which somewhat confirms the last explanation. Some plates work exceedingly well because one fundamental oscillation is a multiple of another fundamental oscillation.

Besides the three fundamental oscillations a piezo oscillator (Figure 2) will give a series of harmonics. They are due mostly to the distortion produced by the tube circuit. They should be distinguished from the higher modes of oscillation when the piezoelectric plate is used as a resonator and for which no harmonic relations necessarily exist.

Calibration of Frequency Meters by Means of a Piezo Oscillator

The method, which is due to Prof. G. W. Pierce (see footnote No. 3), is illustrated in Figure 7. Use is made of the three fundamental frequencies due to the quartz plate, the harmonics of the corresponding electrical oscillations as well as of the harmonics of the auxiliary generator.

The procedure of measurement is as follows:

(1) By means of the inductance L_1 and the variable air condenser C_1 the piezo oscillator is set to one of the three fundamental vibrations of the quartz plate, say for instance, to 80 kc. This is accompanied by using an inductance L_1 which tunes for a certain setting of C_1 to this frequency.

With the piezoelectric plate connected between the filament and the grid, the capacity C_1 is gradually increased until a decrease is noted in the milliammeter in the plate circuit. The capacity of C_1 is further increased until[6] the oscillations stop.

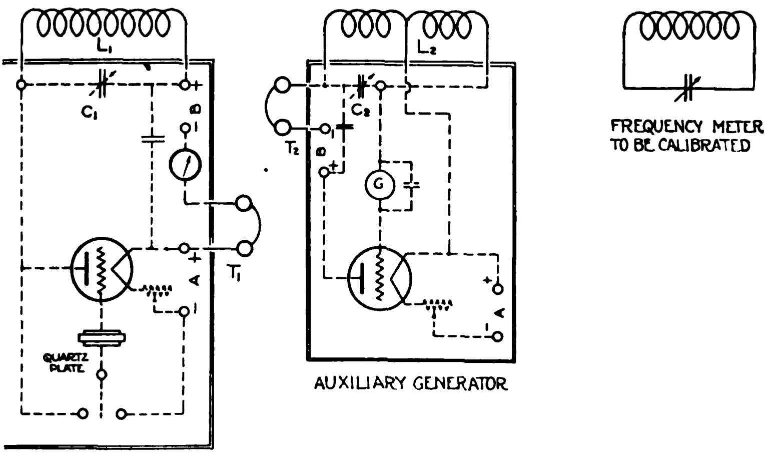

FIGURE 7—Arrangement for Calibrating a Frequency Meter

This happens when the C_1-L_1 branch becomes a capacity reactance and produces a positive resistance between the grid and the filament. The circuit is then no longer regenerative and cannot sustain the oscillations set up by the piezoelectric plate.

The oscillations are started once more by setting the condenser at a point just below the resonance setting. Such a condition will, as a rule, produce a current which is rich in harmonics with a fundamental frequency of remarkable steadiness.[7]

(2) The loosely coupled auxiliary generator is set to the same fundamental frequency by noting the beat note either with the

[6] A milliammeter giving 5 to 10 ma. for maximum deflection is suitable for this work if an ordinary receiving tube is being used with about 80 volts on the plate.

[7] A weight of about 50 grams when resting on a plate vibrating at about 10^6 cycles per second does not change the frequency more than about 10 cycles, and one degree Centigrade change in temperature produces a frequency change of about 20 parts in one million.

telephone receiver T_1 or T_2. Resonance occurs where the critical silence condition (zero beat) within the range of the audible note is secured.[8]

(3) The frequency meter to be calibrated is loosely coupled to the auxiliary generator and its setting varied until the grid milliammeter G of the generator shows a decrease. When this is a minimum the frequency meter is tuned to resonance with the auxiliary generator, *i. e.*, to the fundamental[9] frequency of the piezo oscillator which, for example, is 80 kc.

(4) The frequency of the auxiliary generator is then increased until the next best beat note is heard and the critical silence position adjusted. The grid current decrease produced by the resonance of the frequency meter then gives the calibration for the second harmonic which is for the example 2×80 kc. Without the aid of an amplifier it is possible to go up to about the 20th harmonic. Using one or two stages of audio-frequency amplification for the beat note, it is possible to hear beat notes up to about the 200th harmonic. For ordinary work, the amplifiers can be dispensed with since the twenty harmonics of each of the three fundamental vibrations of the quartz plate give sufficient points. For beat notes due to harmonics of the piezo osillator with the fundamental of the auxiliary generator, it is best to use the receivers T_1 because the beat notes are then louder.

(5) By adjusting the fundamantal frequency of the auxiliary generator to half of the frequency of the piezo oscillator, that is, in the above case to 40 kc., the second harmonic (2×40 kc.) of the auxiliary generator will beat with the fundamental current of the piezo oscillator and the grid current decrease will give the calibration for $f/2 = 40$ kc., if f denotes the fundamental frequency of the piezo oscillator. In a similar way we get calibrations for $f/3$, $f/4$, $f/5$, etc., and this can be readily carried on at least to $f/20$ without the use of an amplifier. For practical frequencies the telephone receiver T_2 should be used since the harmonics of the auxiliary generator are being utilized. Since there are normally three fundamental frequencies, f_1, f_2 and f_3 of the quartz plate, it is evident that one quartz plate is sufficient to

[8] The beat note passes from a high pitch through a low note, narrow silence region, and again up to a higher note, while the condenser C of the auxiliary generator is being varied. The critical silence position can be set within about 15 cycles per second and even somewhat less by means of telephone receivers. If a still greater accuracy is required, a milliammeter can be used instead of phones for watching any of the slower beats between zero and 15 cycles.

[9] By means of the grid milliammeter, the frequency meter can be coupled very loosely to the auxiliary generator with a negligible effect on the frequency.

check the entire range of frequencies used in radio communication. Figures 8a and 8b show characteristic frequency spectra for a circular quartz plate and a rectangular plate, respectively. The exact values are given in Tables III and IV and are computed from only three primary calibrations, namely from the three fundamental frequencies f_1, f_2 and f_3 of the piezoelectric plate.

Example—Suppose a certain frequency meter is to be calibrated for a range between 10 and 50 degrees of the condenser

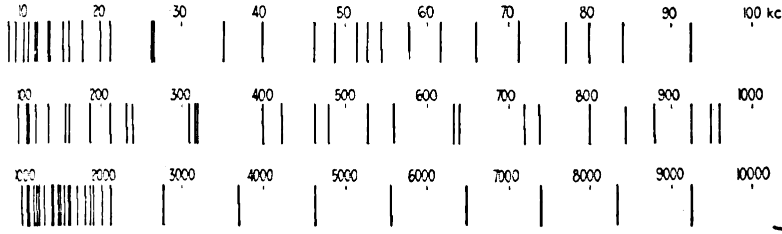

FIGURE 8a—Frequencies Produced by a Piezo Oscillator Using a Circular Quartz Plate 6.307 mm. Thick, and a Diameter of 36.15 mm. The Three Fundamental Frequencies are 75.05, 105.91 and 454.2 kc.

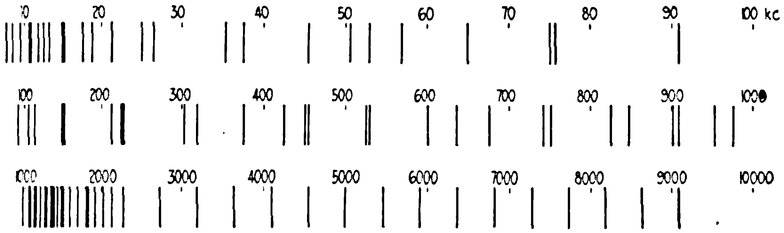

FIGURE 8b—Frequencies Produced by a Piezo Oscillator Using a Rectangular Quartz Plate 3.12 x 25.155 x 31.855 mm. The Three Fundamental Frequencies are 79.925, 105.41 and 924.57 kc.

setting. By means of the auxiliary generator whose settings are approximately known, a few points can be readily found to an accuracy of about one percent. Otherwise the old calibration of the frequency meter can be used or the calibration be estimated from the capacity and the approximate value of the inductance. Suppose that with one of the above procedures it has been found that at 20 degrees the frequency is roughly 226 kc.; at 30 degrees it is 190 kc., and at 40 degrees it is 168 kc. Using the piezo oscillator with the circular plate we find from Table III that 225.15 kc. is closest to 226 kc. and is due to the third harmonic ($3 f_1$) of the lowest frequency of the piezoelectric plate, while 227.1 kc. corresponds to a setting of the auxiliary generator of half of the frequency ($f_3/2$) of the highest natural frequency of the plate.

TABLE III

FREQUENCIES AVAILABLE FROM PIEZO OSCILLATOR A (Circular Plate)

$f_1 = 75.05$ kc.	$f_2 = 105.91$ kc.	$f_3 = 454.2$ kc.
7.505 = $f_1/10$	211.82 = $2 f_2$	1350.9 = $18 f_1$
8.3389 = $f_1/9$	225.15 = $3 f_1$	1362.6 = $3 f_3$
9.38125 = $f_1/8$	227.1 = $f_3/2$	1376.83 = $13 f_2$
10.591 = $f_2/10$	300.2 = $4 f_1$	1425.95 = $19 f_1$
10.7214 = $f_1/7$	317.73 = $3 f_2$	1482.74 = $14 f_2$
11.7678 = $f_2/9$	375.25 = $5 f_1$	1501.0 = $20 f_1$
12.5083 = $f_1/6$	423.64 = $4 f_2$	1588.65 = $15 f_2$
13.2388 = $f_2/8$	450.3 = $6 f_1$	1694.56 = $16 f_2$
15.01 = $f_1/5$	454.2 = f_3	1800.47 = $17 f_2$
15.13 = $f_2/7$	525.35 = $7 f_1$	1816.6 = $4 f_3$
17.6517 = $f_2/6$	529.55 = $5 f_2$	1906.38 = $18 f_2$
18.7625 = $f_1/4$	600.4 = $8 f_1$	2012.29 = $19 f_2$
21.182 = $f_2/5$	635.46 = $6 f_2$	2118.2 = $20 f_2$
25.0167 = $f_1/3$	675.45 = $9 f_1$	2271.0 = $5 f_3$
26.4775 = $f_2/4$	741.37 = $7 f_2$	2725.2 = $6 f_3$
35.3033 = $f_2/3$	750.5 = $10 f_1$	3179.4 = $7 f_3$
37.525 = $f_1/2$	825.55 = $11 f_1$	3633.6 = $8 f_3$
45.42 = $f_3/10$	847.28 = $8 f_2$	4087.8 = $9 f_3$
50.4667 = $f_3/9$	900.6 = $12 f_1$	4542.0 = $10 f_3$
52.955 = $f_2/2$	908.4 = $2 f_3$	4996.2 = $11 f_3$
56.775 = $f_3/8$	953.19 = $9 f_2$	5450.4 = $12 f_3$
64.8857 = $f_3/7$	975.65 = $13 f_1$	5904.6 = $13 f_3$
75.05 = f_1	1050.7 = $14 f_1$	6358.8 = $14 f_3$
75.7 = $f_3/6$	1059.1 = $10 f_2$	6813.0 = $15 f_3$
90.84 = $f_3/5$	1125.75 = $15 f_1$	7267.2 = $16 f_3$
105.91 = f_2	1165.01 = $11 f_2$	7721.4 = $17 f_3$
113.55 = $f_3/4$	1200.8 = $16 f_1$	8175.6 = $18 f_3$
150.1 = $2 f_1$	1270.92 = $12 f_2$	8629.8 = $19 f_3$
151.4 = $f_3/3$	1275.85 = $17 f_1$	9084.0 = $20 f_3$

TABLE IV

FREQUENCIES AVAILABLE FROM PIEZO OSCILLATOR B (Rectangular Plate)

$f_1 = 79.925$ kc.	$f_2 = 105.41$ kc.	$f_3 = 924.54$ kc.
7.9925 = $f_1/10$	115.567 = $f_3/8$	1264.92 = $12 f_2$
8.8805 = $f_1/9$	132.077 = $f_3/7$	1278.8 = $16 f_1$
9.9906 = $f_1/8$	154.09 = $f_3/6$	1358.725 = $17 f_1$
10.541 = $f_2/10$	159.85 = $2 f_1$	1370.33 = $13 f_2$
11.4178 = $f_1/7$	184.908 = $f_3/5$	1438.65 = $18 f_1$
11.712 = $f_2/9$	210.82 = $2 f_2$	1475.74 = $14 f_2$
13.176 = $f_2/8$	231.135 = $f_3/4$	1518.575 = $19 f$
13.321 = $f_1/6$	239.775 = $3 f_1$	1581.15 = $15 f_2$
15.058 = $f_2/7$	308.18 = $f_3/3$	1598.5 = $20 f_1$
15.985 = $f_1/5$	316.23 = $3 f_2$	1686.56 = $16 f_2$
17.568 = $f_2/6$	319.7 = $4 f_1$	1791.97 = $17 f_2$
19.981 = $f_1/4$	399.625 = $5 f_1$	1849.08 = $2 f_3$
21.082 = $f_2/5$	421.64 = $4 f_2$	1897.38 = $18 f_2$
26.352 = $f_2/4$	462.27 = $f_3/2$	2002.79 = $19 f_2$
26.642 = $f_1/3$	479.55 = $6 f_1$	2108.2 = $20 f_2$
35.137 = $f_2/3$	527.05 = $5 f_2$	2773.62 = $3 f_3$
39.9625 = $f_1/2$	559.475 = $7 f_1$	3698.16 = $4 f_3$
46.23 = $f_3/20$	632.46 = $6 f_2$	4622.7 = $5 f_3$
48.66 = $f_3/19$	639.4 = $8 f_1$	5547.24 = $6 f_3$
51.36 = $f_3/18$	719325 = $9 f_1$	6471.78 = $7 f_3$
52.705 = $f_2/2$	737.87 = $7 f_2$	7396.32 = $8 f_3$
54.38 = $f_3/17$	799.25 = $10 f_1$	8320.86 = $9 f_3$
57.78 = $f_3/16$	843.28 = $8 f_2$	9245.4 = $10 f_3$
61.64 = $f_3/15$	879.175 = $11 f_1$	10169.94 = $11 f_3$
66.04 = $f_3/14$	924.54 = f_3	11094.48 = $12 f_3$
71.12 = $f_3/13$	948.69 = $9 f_2$	12019.02 = $13 f_3$
77.04 = $f_3/12$	959.1 = $12 f_1$	12943.56 = $14 f_3$
79.925 = f_1	1039.025 = $13 f_1$	13868.1 = $15 f_3$
84.05 = $f_3/11$	1054.1 = $10 f_2$	14792.64 = $16 f_3$
92.454 = $f_3/10$	1118.95 = $14 f_1$	15717.18 = $17 f_3$
102.727 = $f_3/9$	1159.51 = $11 f_2$	16641.72 = $18 f_3$
105.41 = f_2	1198.875 = $15 f_1$	17566.26 = $14 f_3$
		18490.8 = $20 f_3$

Either one can be used since the points are rather close together. In a similar way 151.4 kc. $=f_3/3$ requires that the auxiliary generator is set to one-third of the frequency of the highest frequency of the piezoelectric plate corresponding roughly to about 50 degrees on the scale of the auxiliary generator. It is convenient to have a rough calibration for the auxiliary generator used. The accurate calibration is then as follows:

(a) The piezo oscillator is excited to the higher frequency which in this particular case is $f_3=454.2$ kc.

(b) The auxiliary generator is set to a frequency of about 151 kc. according to the rough calibration given on the curve of the coil and the condenser C_2 varied slightly until a beat note is heard and then adjusted to the point of zero beat.

(c) The dip [12] in the grid current produced by the resonance of the frequency meter then gives the calibration for 151.4 kc.

(d) By searching by means of C_2 and for the same vibration ($f_3=454.2$ kc.) of the plate in the neighborhood of 225 kc. for a beat note and setting again to the critical silence point, calibration for 227.1 kc. is secured.

(e) Next, the piezo oscillator is adjusted so that the plate vibrates at $f_1=75.05$ kc., and a beat note found near 225 kc. After securing the critical silence point and obtaining the grid current dip, the calibration for 225.15 kc. is obtained.

Beats Between Harmonics and Their Application

When the coupling between the auxiliary generator and the piezo oscillator is somewhat closer but still loose enough to avoid any objectionable interaction between the respective circuits, it is possible to hear weak beat notes, which correspond to 1.25, 1.33, 1.5, etc., times a fundamental frequency f of the quartz plates of zero beat settings for $f/1.25$, $f/1.33$, $f/1.5$, etc. Such beats are caused by the interference of harmonic currents of the piezo oscillator with harmonic currents of the auxiliary generator. This is evident when we express $1.25f$ by $5f/4$ and note that for a fundamental frequency f of the auxiliary generator and its adjustment to zero beat within the region of such an interference the relation

$$5f\frac{=F}{4}$$

[12] For certain couplings (which are not extremely loose) as the frequency meter gets gradually in resonance with the auxiliary generator a low beat note appears again and disappears as resonance occurs. This method can be used for checking the grid dip.

or

$$5\,f = 4\,F$$

holds. Hence the fifth harmonic of the piezo oscillator produces a zero beat with the fourth harmonic of the auxiliary generator. In a similar way the case of $1.33\,f = \frac{4\,f}{3}$ shows that the fourth harmonic of the piezo oscillator is beating with the third harmonic of the auxiliary generator and that for $1.5\,f$ the third harmonic of the piezo oscillator beats with the second harmonic of the auxiliary generator.

Such beats can also be explained by means of beats of beat currents. Suppose the piezo oscillator is excited with a fundamental frequency $f = 80$ kc., and that the fundamental frequency of the auxiliary generator is set to $F = 125$ kc., then an interference takes place between the fundamental currents of the respective high frequency sources. The amplitude variation of the resultant current occurs at the rate of $F - f = 45$ kc., which corresponds to a high-frequency variation which is not audible. Another amplitude variation which is possible is due to the interference between the second harmonic of the piezo oscillator and the fundamental current of the auxiliary generator which produce again a high-frequency variation but of frequency $2\,f - F = 35$ kc. But these two high-frequency currents can beat again and with each other producing an audible current of frequency $45 - 35 = 10$ kc. If the auxiliary genenator is, therefore, varied until $F = 120$ kc., then

$$F - f = 2\,f - F = 40 \text{ kc.}$$

and a zero beat condition is attained which confirms the case of $1.5\,f = 120$ kc. According to this explanation the so-called "spurious" beat notes are due to beats between beat currents, which accounts for the fact that they are, as a rule, weaker than the beat notes giving the settings as expected directly from the theorm of Fourier. The first explanation by means of the interference between the harmonics of each circuit confirms the law

$$a.f = b.F \tag{10}$$

where a and b are whole numbers and is perhaps the most direct way of explaining the phenomenon.

For ordinary work, it seems best to utilize only the main harmonics as shown in Tables III and IV; but if more points are required, for example, two more points between 90.84 and 105.91 kc. (Table III), it is possible to secure them by means of the fundamental plate vibration $f_1 = 75.05$ kc. by using $\frac{5\,f_1}{4} = 93.81$

$$\frac{1 f_1}{3} = 99.82 \text{ kc.}$$

Method Used for Grinding Piezoelectric Plates Accuratey to the Required Frequency

It is possible to grind a quartz plate accurately within a small fraction of a desired frequency, even though the desired frequency is of the order of 10^6 cycles per second. An ordinary standard frequency meter does not have the resolving power to indicate such accurate settings, but the beat method, with a visual beat indicator, can be used. The principle of this method is as follows: An auxiliary generator is required, which can be set at the desired frequency and can maintain it constant for some time. The piezoelectric plate, after first being ground to the approximate frequency according to the frequency formulas given in this paper, is connected as indicated in Figure 2. The holder for the plate is shown in Figure 9b and provides an air

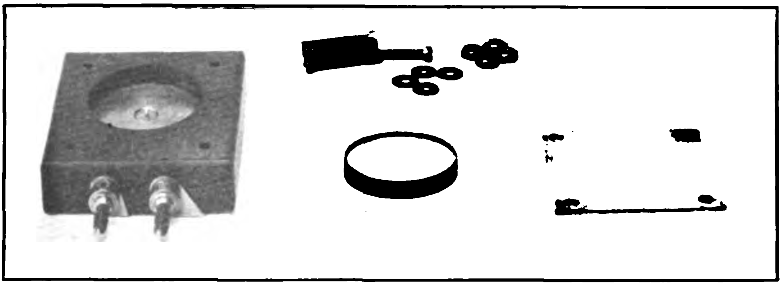

FIGURE 9a—Quartz Plate and Holder for Piezo Oscillator

gap of about one-third mm. between the upper face of the plate and the brass cover. Figure 9a shows the holder open. The plate rests on a polished brass plate. A note will be heard in the telephone receiver of the piezo oscillator, since the frequency of the plate is somewhat off. The plate is taken out of the holder and moved slightly over a grinding plate, using fine emery with water and tried again and again until the note becomes so low as to be difficult to hear. This indicates that the frequency difference is about 15 cycles, the exact frequency depending on the observer. By using a portable galvanometer instead of the phones, the slower beats between 15 and zero cycles can be indicated. It is convenient to connect a portable galvanometer using about 1 to 2 ma. current for the maximum deflection in series with a crystal detector and a coil coupled loosely to both the piezo oscillator

and the auxiliary generator. When the pointer swings to and fro twice in one second, it indicates that the frequency is off by two cycles per second; and if the pointer moves once in two minutes, the frequency is only off by 1/120th of a cycle per second. Accuracies of such a nature are seldom required, and the grinding, according to the formulas given here, is usually sufficiently accurate.

Rough Test for Suitable Piezoelectric Materials

For a rough test of material to determine the suitability for piezo oscillators, a plate or disk is cut from the material which

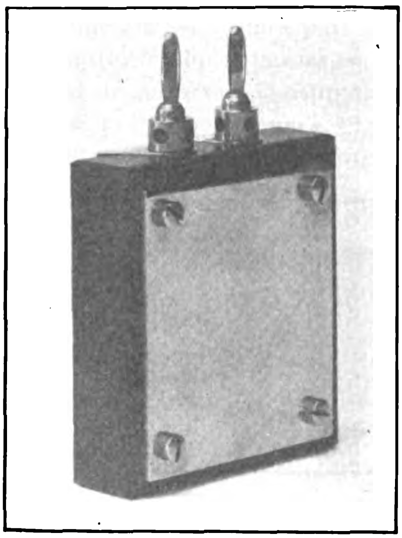

FIGURE 9b—Quartz Plate Holder for Piezo Oscillator Assembled

does not need to be exactly parallel), and this plate is inserted between the plate and the grid of an auxiliary generator which has a telephone receiver in the plate circuit. If the sample is suitable it will give several distinctive absorption noises while acting as a resonator. The frequency of the generator is gradually varied and a click will be heard for the different modes of resonator actions.

Method for Controlling Power by Means of Piezoelectric Plate

Since it is not possible to generate much power[13] in the circuit in which the quartz plate is connected, an amplifier which is

free from self-oscillation must be used. An arrangement is shown in Figure 10. The piezo oscillator is set for maximum output so that its fundamental current is almost sinusoidal and pronounced. This is done by varying the capacity of C (circuit as in Figure 2), until the oscillation is about to stop. The amplifier tube (50-watt tube) as well as the power tube (250 watts) use negative grid voltages so that they deliver no plate current at times when the piezoelectric plate is not vibrating. These tubes are therefore only loaded at such times as they are required to deliver power. Experiment shows that there is no transfer of power back to the piezo oscillator, and that the arrangement does not generate but merely amplifies the current of the first circuit. This can be demonstrated by keying the switch K. With the

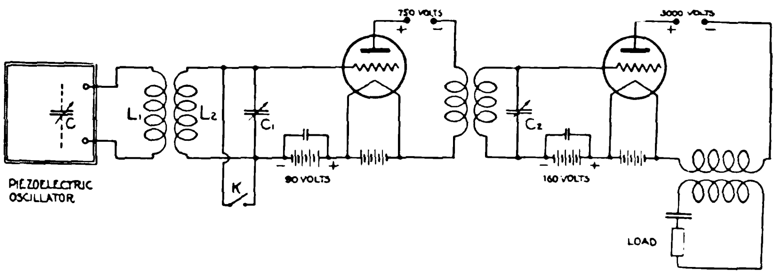

FIGURE 10—Control of Power by Means of Piezoelectric Oscillator

switch open, incandescent lamps consuming 250 watts in place of the load burn brightly; with the switch closed they are extinguished. The arrangement indicated works well. To control more power, one or more stages may be added. The control of power is of special interest for high-frequency work (2,000 kc. and above), where the constancy of the frequency is otherwise greatly impaired by body capacity, etc. Special means have to be used then to produce the very high-frequency oscillations. One is, for instance, by using a suitable auxiliary voltage in the grid circuit of the piezo oscillator. If an appropriate choke coil is used instead of the auxiliary voltage in the grid branch, care muct be taken that the tube does not produce oscillations which are due to the constants of the circuit.

AUDIO-FREQUENCY CURRENTS FROM PIEZO PLATES OF MODERATE SIZE

Since the frequency in kilocycles of a quartz plate is roughly 3,000 divided by the dimension in mm. along which the vibration occurs, it is evident that a very large plate has to be used for producing audio currents. Audio frequencies can, however, be

obtained when the interference vibrations of two high frequencies are produced, giving beats of audio frequency. There are three methods for accomplishing this.

(1) Use of two piezo oscillators. Suppose one marked A has a fundamental frequency of 100 kc. and another marked B a frequency of 99 kc. Each plate is connected in a separate piezo oscillator as shown in Figure 2. The two circuits may be coupled to a third circuit with a detecting device and will give an audio frequency current of 1 kc. Either of the two circuits may be used also as a detector, and the audio frequency taken directly from one of them. For ordinary work this gives the audio-frequency currents readily. However, one circuit has the tendency to affect the other, that is, by adjusting the amplitude of one high-frequency component the frequency of the audio current varies somewhat, often as much as 10 to 20 cycles per second. This is a disadvantage when a high precision is required unless the circuit is calibrated and used only for certain amplitudes (condenser settings of the respective piezo oscillators).

(2) Use of two quartz plates in the same circuit. The two plates A and B may be connected in parallel but in separate plate holders and in the same circuit which gives directly the audio-frequency current. The audio-frequency oscillation is then a little harder to start since both high frequencies are produced by the same tube. It may happen that one of the two high-frequency vibrations builds up faster than the other and uses all of the available power and annuls the effect of the other oscillation. This is sometimes accompanied by a short whistle during which period both oscillations exist. Sometimes there is no whistle at all, in which case only one oscillation starts up.

By using frequencies in the neighborhood of 100 kc. and higher, it is easy to find a plate inductance which starts both frequencies and produces the desired audio-frequency current. If it is done properly the audio frequency can be produced for a range of condenser setting (about 10 to 20 degrees) and adjusted to a point for which maximum loudness exists. This is the point for which the oscillator should be calibrated and used.

(3) Use of a single quartz plate. A single piezoelectric element may be used for producing the audio-frequency current directly. To accomplish this a plate is ground first for producing the component vibration A and then a small step ground in it[14]

[13] Not more than about 6 watts for a plate of average rating.

[14] The height of the step is exceedingly small so that the quartz has still the shape of a plate to the eye and can be used in an ordinary plate holder with an air gap of about 1/3 mm.

as indicated in Figure 11 in order to superimpose on it the high-frequency vibration B. The plate is used in the ordinary way, (Figure 2) and works well. The oscillogram of Figure 12 shows the beat current which produces an audible note. Figure 13

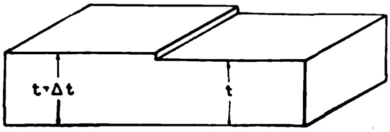

FIGURE 11—A Piezoelectric Plate with a Minute Step in it for Audio Frequency Currents

gives an arrangement using a plate as indicated in Figure 11, when more output is required. It is an arrangement which is self-starting, that is, a fixed condenser is used in the piezo circuit and the audio frequency current will start upon closing it. The

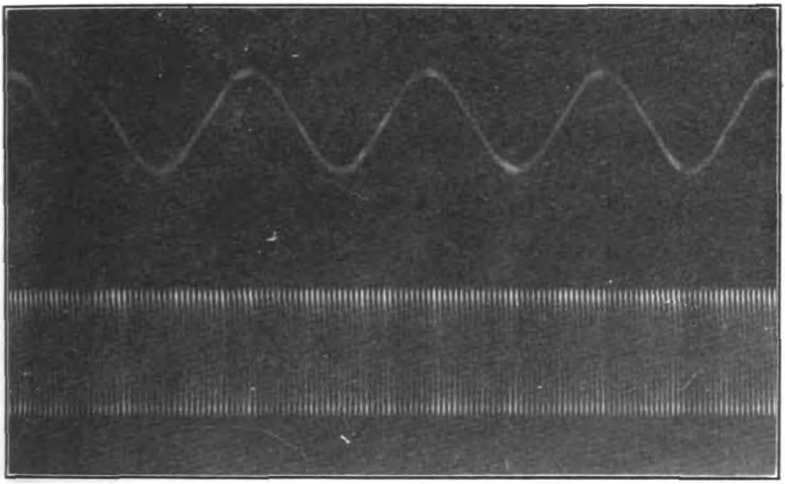

FIGURE 12—Beat Current Produced by a Single Small Piezoelectric Oscillator. (f .. 1912.1 Cycles per Second, Upper Oscillogram is the Timing Wave.)

arrangement of Figure 13 was used for producing the wave shown in Figure 12. For the oscillographic work and other applications it is also possible to use the piezoelectric plate circuit directly in the output circuit as long as not more than about 6 watts are required. It is to be noted that the output of an audio-frequency oscillator is somewhat smaller than when only one component

current is flowing. It is not necessary always to use a load resistance across the output branch as indicated in Figure 13. Any amplifier circuit arrangement will be satisfactory.

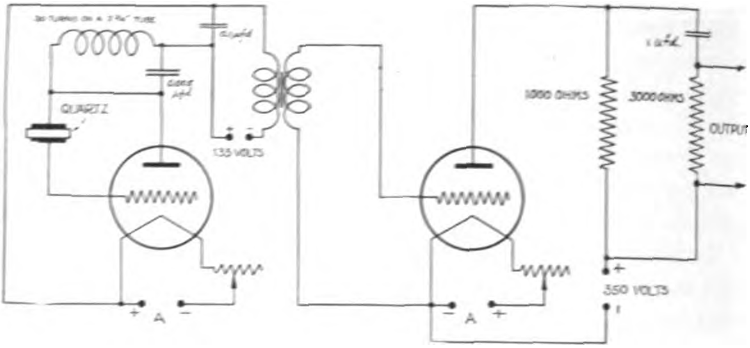

FIGURE 13—Audio-frequency Oscillator Which is Self-starting

MISCELLANEOUS APPLICATIONS

By using the method herein described, it is possible to grind a plate to any suitable frequency. It is, therefore, possible to design the equivalent of a second pendulum or any other timing device. The disadvantages described in connection with the first method for producing audio-frequency currents can be used to advantage for making a radio or audio-frequency generator whose frequency can be varied somewhat without regrinding the piezoelectric plates.

A change of a few cycles and less in a plate for radio frequency currents is due to a change in dimension which can not be noted with a micrometer. It can, therefore, be used for measuring very small variations in the thickness of piezoelectric materials.

Using a sphere of quartz the optical axis can be roughly determined electrically (no direct electrical effect along it) as well as the main piezoelectric axis by placing the sphere between two cup-shaped electrodes and noting the strength of any resonator effects when placed along different diameters of the sphere.

Working backwards, using the electrical data (frqeuency), and the dimensions, it gives a means for finding certain mechanical properties of the substance such as its elasticity from the velocity and the density.

Using a vibrating piezoelectric plate in front of a fine slot or another vibrating plate, a shutter can be designed which opens and closes at a very high rate. This may open up a new field in experimental optics for direct and reflected light rays, and give a means of determining the velocity of light.

Conclusions

(1) Experiments with quartz plates have shown that they can be used in an electron tube circuit for producing radio-frequency currents of fixed frequencies bearing a definite relation to the dimensions of the plate.

(2) The piezo oscillator can be used together with an auxiliary generator for standardizing a frequency meter.

(3) A single piezoelectric plate can be employed as a standard for the entire range of frequencies used in radio communication.

(4) By using special arrangements a small plate can be employed for producing audio-frequency currents.

(5) Methods are given for grinding a plate accurately to a given frequency.

(6) Formulas are given for designing plates to a desired frequency to a fair degree of accuracy.

(7) Other miscellaneous applications are described.

SAFEGUARDS FOR THE RADIO INVENTOR*

By

Everett N. Curtis

(Member of New York Bar and Lecturer on Patent Law at Columbia University)

My topic assigned for this evening concerns the safeguarding of the inventor who, ignorant of patent law, may neglect the taking of those steps or precautions which he may at some time find of infinite value in the preservation of his rights. The inexperienced inventor as a rule is the victim of his own imagination or his own unfounded suspicions, in that he is usually watching for some patent pirate just around the corner whom he fancies is looking for the opportunity of swooping down upon him and of taking away the coveted prize. He is, therefore, fearful of disclosing his invention to anybody. He is suspicious even of his friends. It may be in rare instances his friends are such as to warrant such suspicions, but more often the inventor's secretiveness results in his neglecting to preserve proper evidence of his date of conception and his reduction to practice, so that in case of a contest as to who is the prior inventor of a certain invention, he is unable to offer good and sufficient proof of the actual facts, and loses the contest, not to a pirate but to a rival inventor with the requisite evidence.

Some inventors have the idea that patenting an invention is a sort of marathon race to the Patent Office. They go to a motion picture house and see a fearsome drama, in which the inventor after undergoing and surviving many perils, finally races up the steps of the Patent Office one jump ahead of the villain and deposits his patent application just in time to save the day. In the same drama, with the same marvelous speed, unknown in practice, the Patent Office immediately examines the application and prior art, and the next day issues the patent. As most of you know, nothing could be further from the truth than this. While it is of advantage to be the first to file an application in the Patent Office, a prior inventor if he be diligent in

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reducing to practice and in filing his application will, nevertheless, prevail even though his filing date is subsequent to his rival, but not two years or more prior to the issue date of his rival's patent. Furthermore, getting a patent is not a speedy process. Ordinarily it is several months before a patent application is reached by the examiner and several years before the patent actually goes to issue.

It sometimes happens that where two or more men have been working to bring an invention to a successful issue, it is determined by them to file an application for a joint invention. The central idea may have been the creation of one of them, but the others have contributed time, effort, and mechanical skill, and it seems only just, all things considered, that the application should be filed in the names of all of them. This is often a snare and a delusion. Joint inventors are those who jointly create a single invention. If the creation of the invention is the product of a single mind, no amount of co-operation of others in reducing the same to practice can change the original individual creation into a joint invention. It is rarely that two or more persons can unite together in creating a single invention. In many cases, where so-called joint inventors are subjected to cross examination, it develops that there was but one inventor and that the others were not inventors at all and the patent is declared void for this reason. Great care should, therefore, be taken where an inventor deems himself a joint inventor. He should carefully sift the whole situation to determine whether or not after all there was really joint invention, and only after mature consideration should a joint application be filed.

It is of great importance to the radio inventor to keep and preserve careful records. He should have note books in which to make sketches of such inventions as may occur to him from time to time, together with notes of explanation. These should all be dated. If he thinks that any of these are of material importance, he should secure the signature of witnesses, and also have made up dated drawings by a competent draftsman fully illustrating his construction. Another method is that of a drawing and affidavit clearly describing the same and setting forth the fundamental features of the invention. Still another method is that of writing dated letters disclosing the invention to a relative or to a friend, particularly where the envelope bearing the postmark is preserved. It is also of importance to save if possible any models or full-sized machines together with working drawings, bills for parts, and records of actual tests. All these

matters go to show the date of invention, the date of disclosure and the date of reduction to practice.

It is not the date of filing an application for patent which controls in a contest as to who is the first inventor. It is he who can show by a preponderance of the evidence that he first conceived the invention and with due diligence reduced it to practice, that will be declared the first inventor and entitled to the patent.

Thus, for example, in the well-known litigation over the Armstrong Feed-Back Patent in the Federal courts in the second circuit, Armstrong was able to prevail over all other alleged inventors making claims to his invention by reason of the decisive character of his proofs establishing the fact that he was the first inventor. The inventor's mere assertion, standing alone, that he invented his device on a certain day amounts to nothing No court will ever find the date on invention to be established on the uncorroborated testimony of the inventor. It is, therefore, of the utmost importance that this evidence be secured and preserved as heretofore indicated or the inventor will have to bear the penalty of his neglect. So also must the inventor's reduction to practice be fully substantiated. If sufficiently early in point of time the date of the filing of the application may be relied upon as a constructive reduction to practice, but it is better, all things considered, to try out and demonstrate at the earliest possible moment under the conditions of actual commercial use the operativeness of the invention. It is evidence of the tested reduction to practice which counts most heavily with the courts, and the one which most effectively disposes of the contention of abandoned experiment.

An inventor cannot afford to sleep upon his rights. If he has made an invention it is his duty to reduce it to practice at the earliest possible moment and to apply for a patent. The theory of reward to an inventor by the grant of patent is based upon some obligation in his behalf. A patent is a contract. In consideration of the enjoyment of the exclusive right of the invention for the period of 17 years, the inventor makes a full disclosure to the public in order that at the end of this period the public may have thrown open to it the full knowledge of and right to make, use and sell the invention. In other words, an inventor must play fair with the government. If he makes an invention and takes no steps toward reducing it to practice or demonstrating its practical use until a rival inventor enters the field, he may lose his right. If he stands idly by and permits others

to use his invention without protest, his acts may be construed as a constructive abandonment, and his rights to a patent are forfeited. Where this right is once abandoned by the inventor, it cannot afterward be resumed at pleasure, as where gifts are thus made to the public, they become absolute.

Another important matter neglected by inventors is the necessity of making a full disclosure of the invention in the application as originally filed. While the fullest opportunity of amendment both of the specification and claims is permitted in elucidating, amplifying and correcting the same, it is not permitted to incorporate new matter. The inventor, therefore, should not rely too much upon his attorney for this original disclosure. He should read and re-read the specification and claims as drafted by his attorney to make sure that his invention is fully and correctly set forth. It is better by far to say too much than not enough. Too much may easily be cancelled, but if the inventor says too little, he will be correspondingly limited. The claims are also important. The claims are the life of the patent. The inventor is required by law particularly to point out and distinctly claim the part, improvement or combination which he claims as his invention. Nothing is secured to the patentee unless there be in his patent a valid claim covering it.

What is not claimed is by implication given to the public, so claims should be drafted to give the inventor the broadest possible protection. The broadest claim of the patent is the claim containing the fundamentals of the invention, or the invention reduced to its lowest terms. The inventor should realize this and carefully examine the claims with this in mind. The drawings should be carefully checked, and enough figures should be employed fully to illustrate the invention. Mistakes are likely to creep in. Care must be taken to correct them before the patent is issued. If a drawing is defective, as for example, where an inoperative hoop-up is shown, the effect on the patent may be disastrous and may result in the patent being declared to be void for want of utility. The drawings, specification and claims are all considered together in determining the scope of a patent, and the claims are to be fairly construed so as to cover the invention if possible, and save it especially if it be a meritorious one. Claims are to be construed in the light of the specification and in view of the prior art. If the invention is primary, a broad interpretation is to be given, but if the art is close, the claims are to be narrowly construed.

This brings us to the consideration of the nature of patent

rights. For an alleged invention to be patentable, it must be new, it must have utility, and it must involve the exercise of the inventive faculty. What the inventor gets by his patent is a negative right, that is, the right to exclude others from making, using or selling his invention, without his permission. If his rights are infringed, he may obtain relief by a suit at law for damages or by a suit in equity for an injunction, profits and damages.

A patent right is not a natural right. It is entirely the creation of statute. For many years of the earth's history, the inventor had no reward. Patent systems taking the inventor into consideration have been of comparatively recent growth. Even under our own patent laws in the early history of our country there were but few patents granted. Practically all of our great advance in invention has been accomplished within the last fifty years, and is due largely to the encouragement given to the inventor by patent laws the world over. In most foreign countries, the obligation is imposed upon the patentee of working the invention under penalty of forfeiture of the patent. Such obligation has never been imposed by the laws of this country, and this may be one of the reasons why invention here is so prolific and why so many applications for patents are filed in the U.S. Patent Office.

The question of novelty plays a considerable part in determining the scope of a patent, and accordingly the prior art must always be considered in drafting a patent application. It is useless to attempt to cover in a patent that which is old and well known to the art. An inventor is presumed to know or hold to the knowledge of what has gone before, and his claims are limited or avoided accordingly. It is well, therefore, for an inventor to educate himself in the particular art to which his invention belongs. This he may do by reading the literature accessible to him, and by having searches made of the files of the Patent Office at Washington.

The two-year statutory periods are important to the inventor. The patent statute provides that a prior printed publication or patent published in this or in any foreign country more than two years prior to the filing of the inventor's application here, or a public use or sale of the invention in this country more than two years prior to such date, shall operate as a bar to the issuance of the patent. This language not only applies to publications and uses of other persons than the inventor but also to the inventor himself. Care should accordingly be taken by the inven-

tor not to permit these two-year periods to run against him, either by rushing into print or by permitting a public use of his invention and then neglecting to file his application within the time. Furthermore, the inventor, if he contemplates filing applications abroad, must be careful not to publicly publish or use the invention here in advance of the making of such applications or he may lose valuable rights or perhaps all rights relating thereto.

Some inventors have thought that by concealing their inventions, as in the case of a secret process, to delay over a considerable number of years the filing of an application for a patent until it was determined that secrecy could not longer be maintained. The danger of this is that courts have held in a number of cases that such conduct on the part of the inventor constituted abandonment and forfeiture of the right to obtain a patent.

In the absence of a special agreement, inventions made by an employee belong to him personally. But where he is employed in a certain line of work to invent, his inventions belong to his employer. That is, while the mere fact he is employed by another person does not preclude him from making improvements in machines with which he is connected and making application for patents therefor as his own personal property, yet if he be employed to make such improvements the right to such patent belongs to his employer, since he is merely doing what he was employed to do. Even if he be not employed to invent, if he uses the property of his employer, and the services of other employees to develop and put into practical form his invention, and permits his employer to use the invention without protest, a shop right or license may result to the employer. Contracts with employers are usually drawn by the employer, and are construed most favorably to the employee. A contract requiring an inventor to turn over *all* the inventions he may make without limitation to his employer is void as in restraint of trade and against public policy. Such agreements must be limited to the line of endeavor in which the employee is engaged or by the scope of the employer's business, and if it be desired that the employee should turn over such inventions or applications therefor to the employer, words of assignment or the equivalent should be unequivocally set forth. Otherwise, on a suit for specific performance, the court might decline to act because of uncertainty.

At the present time, there are coming before the Courts many questions of contributory infringement with respect to the selling parts which may be used in a patented receiving or send-

ing set. If any individual sells an entire set which is an infringement of the set, there is no trouble in fixing the responsibility, but where one person assembles parts for such set furnished by others, it is a matter of considerable difficulty to show the necessary concert of action the law requires in this connection. If the part supplied is incapable of any use except an infringing one, intention to infringe is presumed, but where such part may be otherwise used, positive proof must be adduced to show such intention. In other words, in contributory infringement, intention to infringe is an important element and must ordinarily be shown by affirmative evidence, such as declarations by the person supplying the part that the same is to be incorporated in the infringing set. Merely selling the set unassembled, however, is not sufficient to avoid the charge of infringement, as is shown in a recent case decided by the U. S. District Court of the Southern District of New York, where the court said that "it is an infringement to divide the patented machine into parts ready for assemblage even though the party who is to use them must put them together." In an old Federal case, it was early decided that if an infringing machine is made as an experiment merely, it does not infringe former patents. To constitute infringement, the making must be with an intention to use for profit, not for the mere purpose of a philosophical experiment. Can it be said in the individual case where a person purchases parts from various dealers to form part of an experimental set used at home that such dealers are contributory infringers, even if they knew of such experimental use? If an experimental use is not an infringement, how can a contributor to such use be an infringer? If every builder of a home set is an experimenter, and dealers who contribute parts are not to be held guilty of infringement, will not the door be opened considerably and the field of the patentee correspondingly restricted? These and other questions are coming before the courts and upon their proper solutions depends the future of the radio industry so far as concerns dealers and users.

Such are the chief dangers against which the inventor should guard himself. They are dangers which in the main can be met or largely alleviated by a little care on the part of the inventor, who should remember that although inspiration may come from on high, a little attention to the humble position of one's feet on the earth is also bound to yield beneficial results.

SUMMARY: Precautions for the radio inventor who is not associated with an organization which includes a patent department, with explanation why such precautions are necessary.

"KDKA"

By

D. G. Little and R. L. Davis

Radio Engineering Department, Westinghouse Electric and Manufacturing Company

Introduction

KDKA, up to March 1, 1925, has been described in previous papers before the Institute. It is the purpose of this paper to bring the history up to date by describing the equipment now in use, both for regular broadcasting and for short-wave international broadcasting and relay work. The short-wave transmitter, employed for interworks telegraph service, will also be described.

General

The rapid development of broadcasting, both long and short wave, indicated that the space available at the East Pittsburgh Works would soon become inadequate for further expansion. A place was, therefore, selected about two miles from the old location, on high and relatively level ground, free of buildings and structures that might influence radio transmission, and a building laid out that would house the proposed equipment for all transmission activities. The antennas and buildings cover a space approximately 300 x 500 feet. Figure 1 shows the station building and the antennas. The station building is located in the center of this plot and is a basement and one story brick structure 25 x 65 feet, with a wing on the front 20 x 30 feet. The offices, storerooms, shop, and audio frequency control room are located in the wing; while the radio equipment is placed in the main part of the building, the long wave at the South end, and the short wave at the North end. The power apparatus, such as motor-generator sets for filament heating, transformers, filters, control apparatus, and storage batteries, are placed in the basement, leaving the main floor for the rectifier, modulator, and oscillator vacuum tube frames.

Presented before the Institute of Radio Engineers, New York, September 2, 1925. Received by the Editor October 5, 1925.

to use his invention without protest, his acts may be construed as a constructive abandonment, and his rights to a patent are forfeited. Where this right is once abandoned by the inventor, it cannot afterward be resumed at pleasure, as where gifts are thus made to the public, they become absolute.

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Power for the station is obtained through underground cables from two separate substations of the Duquesne Light Company. A substation in the basement of the building transforms this power of 4,000 volts, three phase, 60 cycle, into 220 volts, three phase, which is then distributed to the radio equipment.

The short wave or 64-meter transmission work was moved to the new building during the summer of 1924, and has been in use since that time.

Careful tests were made at the new location before the 309-meter apparatus described in this paper was put in regular oper-

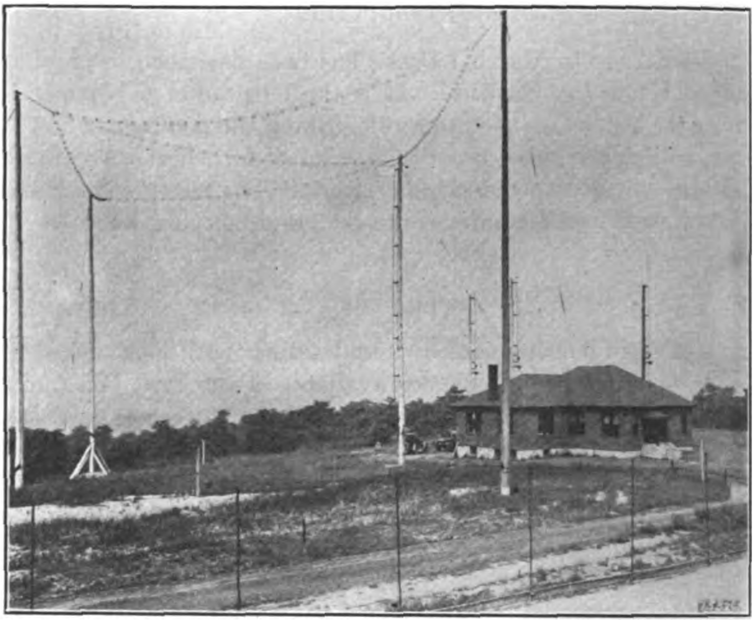

FIGURE 1—General View of "KDKA" Station

ation. On the night of March 19, 1925, alternate numbers of the program were run from the old station at East Pittsburgh, and from the new station. The program selections were numbered and reports requested from Westinghouse representatives in all parts of the United States. The same power was put into the oscillators at the two stations, thus checking both the locations and the antenna systems. The results of this test indicated that the new location was considerably better than the old. The majority of nearly 100 observers reported an increase in the signal strength received, particularly at distances beyond 300 miles; and as the new antennas had an effective height somewhat less

than the old, the new location on high, level ground is a considerable improvement over the old location in the valley at East Pittsburgh.

Figure 2 shows in schematic form the layout of circuits.

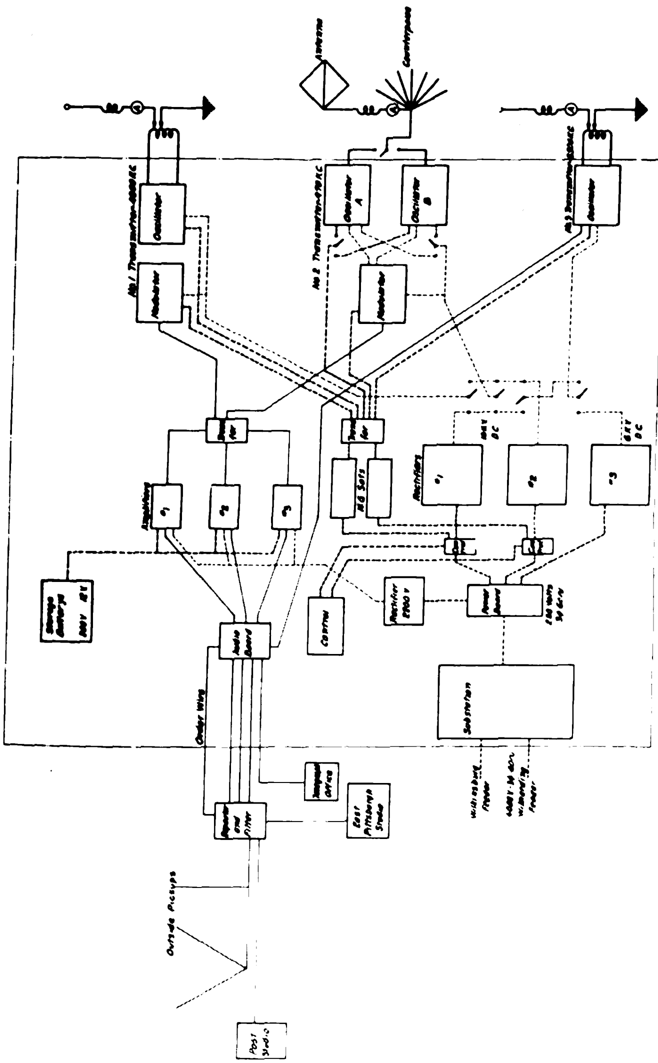

FIGURE 2—Schematic Circuit Diagram

No. 2 Transmitter

The equipment employed for regular broadcasting at 970 kc., 309.1 meters, is known as No. 2 Transmitter, and is here described.

Antenna. The 970 kc. antenna system differs somewhat from the conventional flat-top type. This antenna has been

shown in Figure 1. Four spruce poles, 80 feet in height, support five cages, each 100 feet long. The vertical conductor is a $1\frac{1}{2}$-in. diameter copper tube rigidly supported on porcelain pillar insulators by the pole nearest the station building. Three cages are connected to the top of the vertical lead and extend horizontally, with angles of 60 degrees between them, to the remaining three poles, which in turn are connected by two cages. Each cage is made up of eight No. 10 copper wires on micarta ring spacer 6 inches in diameter. This makes an antenna with flat top of low copper loss. The high potential points are near the middle of the two outer cages, so that insulator loss is also minimized. The small loading coil seen in Figure 3, and ammeter, are con-

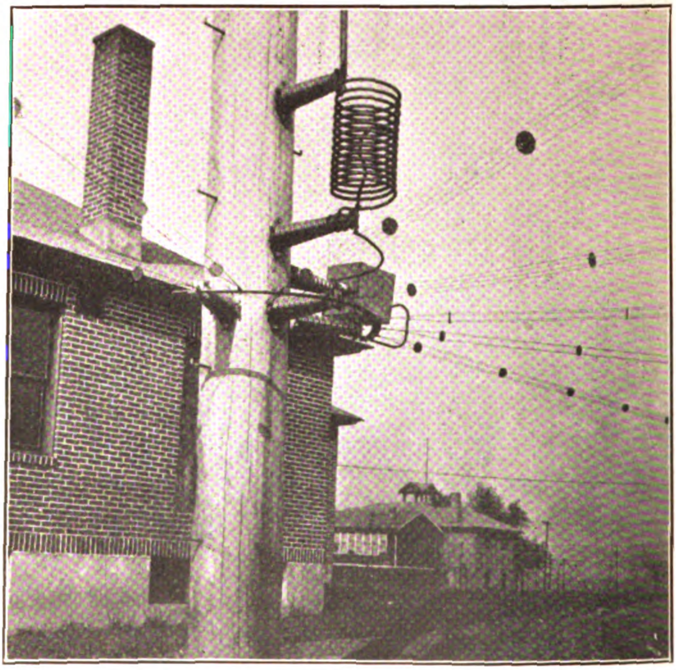

FIGURE 3—Antenna Loading Coil and Ammeter

nected in series to the lower end of the vertical lead, and the current then flows into the counterpoise, which consists of seven cages, spreading in fan shape from the main pole. Each counterpoise cage is made up of four No. 10 copper wires on 3-inch diameter micarta spacers. The copper tube coupling lead to the transmitter is connected just below the ammeter.

The natural period of this antenna structure is 281 meters.

The total resistance measured at 970 kc. is 10.8 ohms and the effective height approximately 20 meters. The resistance curve is given in Figure 6.

Apparatus—Oscillator. There are two oscillator frames, one employed as a spare part. The oscillator frames each provide mounting for eight WO-41 (see Figure 5), 10-kw. water-cooled

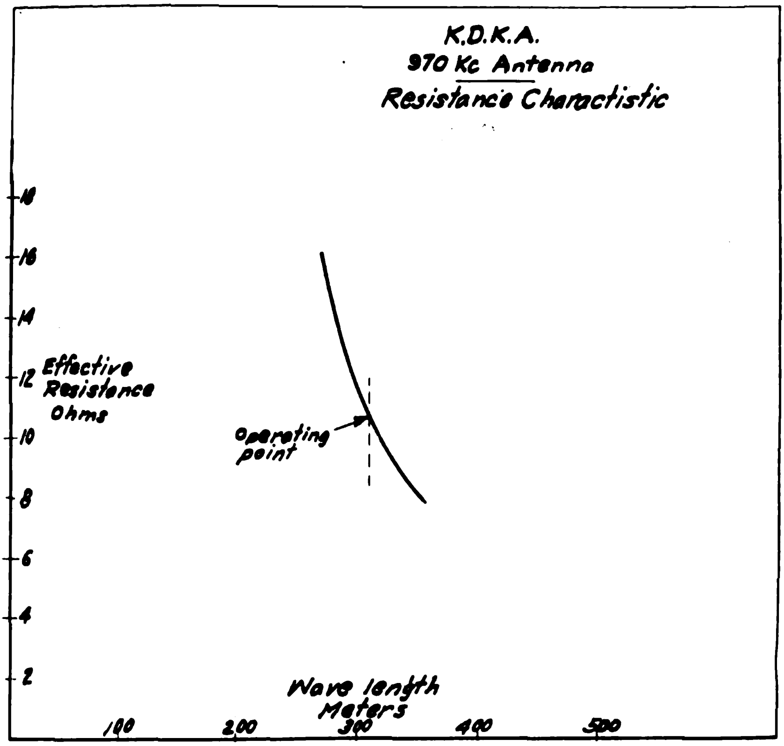

FIGURE 4—970 Kc. Antenna, Resistance Characteristic

tubes in two groups of four tubes. Figure 6 shows the mechanical details. The four tubes are clamped to a common plate support and treated as a unit. All oscillator and modulator tubes are furnished with filament power from the motor generator sets, shown in Figure 7. A filament voltmeter and plate ammeter are mounted on the front of the frame. The primary oscillating circuit is arranged in the rear of the tubes and consists of a 500 $\mu\mu$f. air condenser and a 52 micro-henry inductance mounted above. Fine adjustment of frequency is obtained with a single turn variometer, mounted at the end of the primary circuit inductance. This is adjusted approximately by means of the fre-

quency standard wavemeter, shown mounted on the wall in Figure 6, and exactly to zero beat with a small oscillator provided with a quartz crystal ground to 970 kc. This arrangement enables frequency adjustments of a precision unobtainable in any

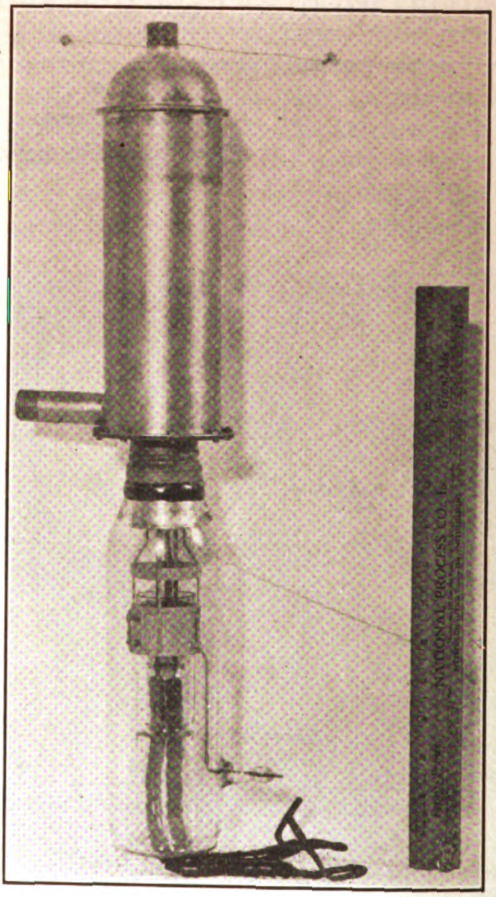

FIGURE 5—WO-41, 10 Kw. Transmitting Tube

other way. Under normal conditions, KDKA should be within 100 cycles of the frequency assigned to it.

Figure 8 shows the connection diagram of the oscillator and modulator circuits as employed at KDKA. The modulation choke is not shown in this diagram, as it is treated as a group with the filter system and appears on that diagram. For clearness, only one oscillator and two modulator tubes are shown.

However, during actual normal operation, to which most of the following data applies, four type WO-41 tubes are used as oscillators and nine as modulators.

Plate and grid couplings to the primary oscillating circuit are of a conventional type, which is familiar to radio men.

Antenna coupling to the primary circuit is effected through a single lead, having a choke coil in series with it, and connected, between the two circuits, at almost any convenient point, other

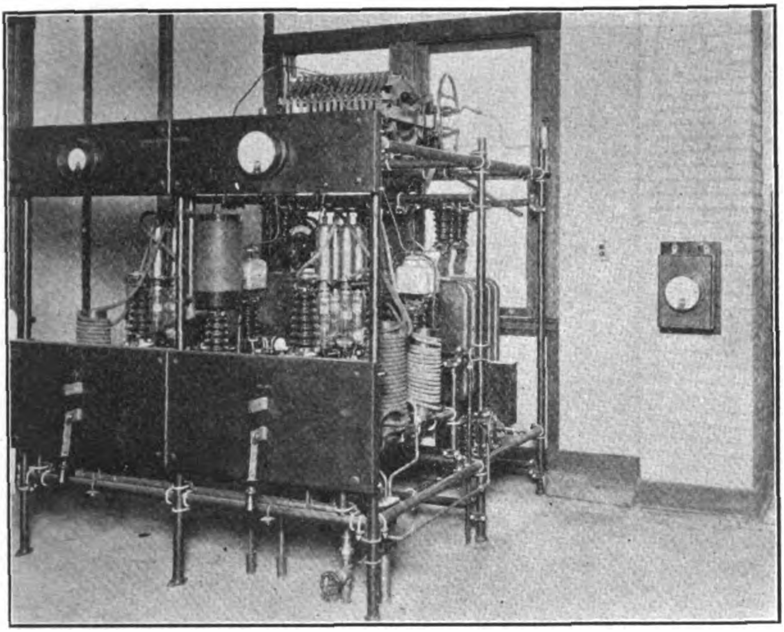

FIGURE 6—970 Kc. Oscillator Frame

than the ground. This coupling method is subject to easy adjustment, and the small coupling lead, since it carries only a small current, can be carried distances which would be prohibitive for the main antenna leads.

The choke also acts to suppress harmonics, as its impedance is proportionally greater for the high frequencies. No ground is used on the antenna itself, as it is thought best to permit it to oscillate freely about its own electrical center rather than attempt to constrain it by an actual ground, location of which is inconvenient and subject to slight changes.

The use of water-cooled tubes permits a simple means to be employed for determining the efficiency and losses of the tubes

and connected circuits. By measuring water flow and temperature rise to determine the energy given off under different conditions, and considering this in connection with plate input, grid leak losses and heating of the plates, due to filament alone, valuable data may be obtained. In this manner, the primary circuit losses and antenna input can be evaluated quite accurately. The measurements made by this method for antenna and primary circuit resistance check measured values to a close degree. For example, the antenna resistance measured in a

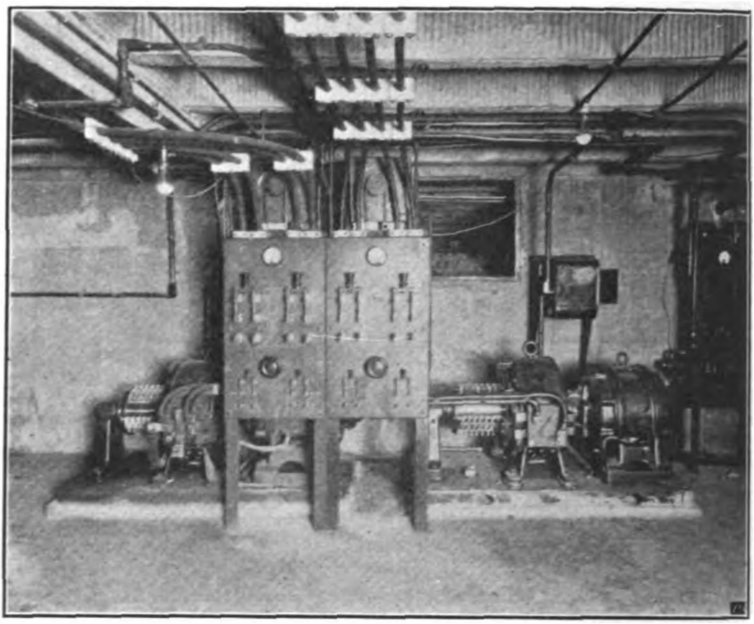

FIGURE 7—Filament Motor-Generator Sets

more conventional manner was 10.8 ohms, and by the heat loss method was 10.73 ohms.

The net oscillator efficiency, considering the direct current input and output to the antenna, obtained from the heat loss method was found to be constant at 67 percent over a wide range. This is as it should be if good modulation is to be obtained, as the whole condition for modulation is based on proportional antenna current and plate volts, which, of course, means constant efficiency.

Gross plate efficiency for the oscillator units is 70 percent, which, with the losses of the grid leak of 200 watts and primary

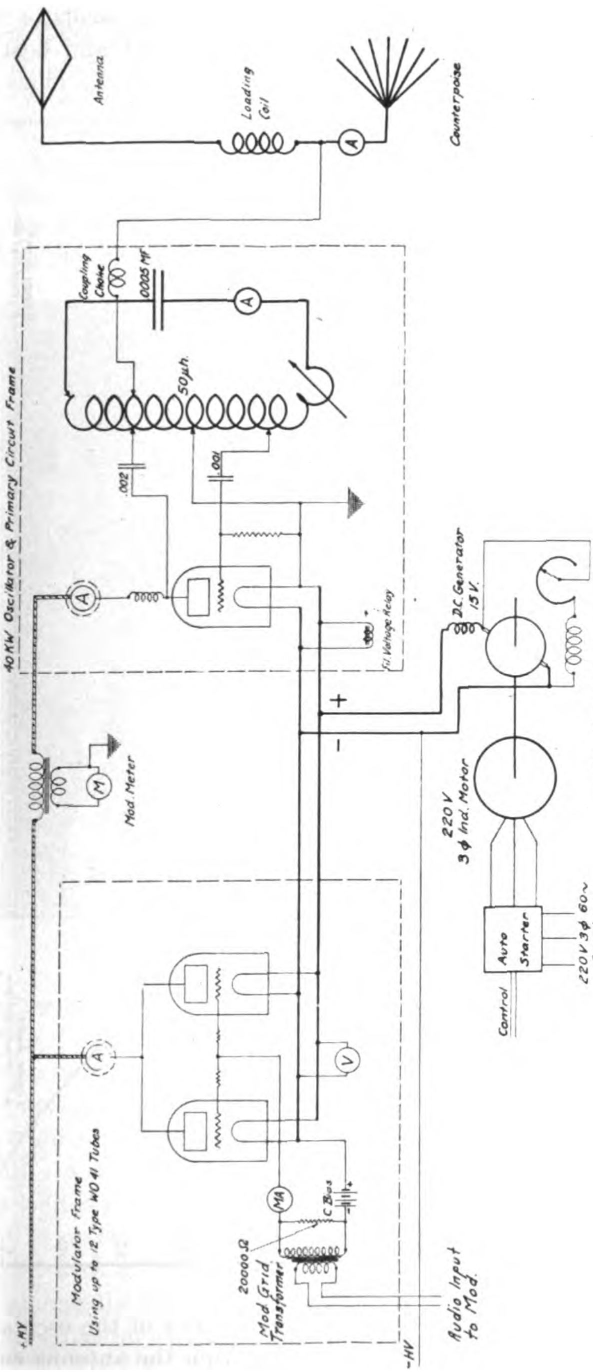

FIGURE 8—Circuit Diagram, Oscillator and Modulator

circuit I^2R loss, brings the net efficiency of the oscillator to 67 percent, as stated before. Direct measurement and heat loss means, both give a primary circuit resistance of 0.3 ohms.

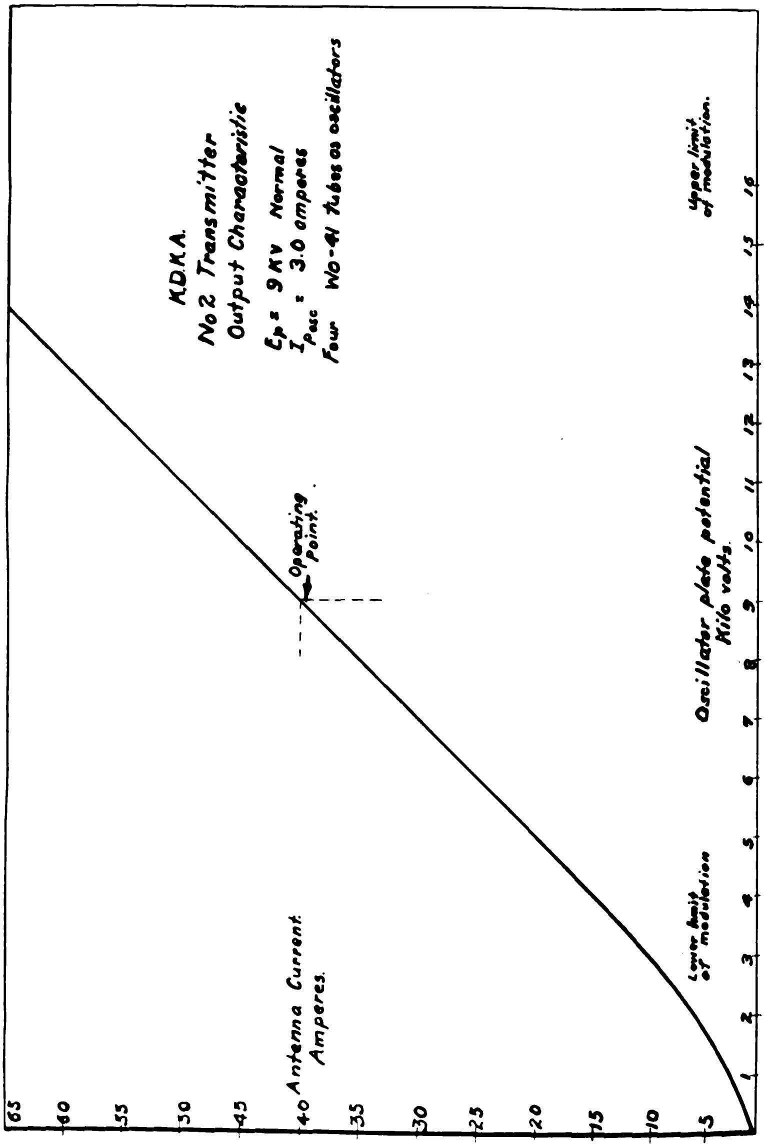

FIGURE 9—Antenna Current—Oscillator Plate Voltage Curve

Another check, showing that the efficiency of the oscillator is constant over a wide range, is obtained from the antenna current plate voltage curve, as shown in Figure 9. This is a straight line

over the entire distance, 2,500 to 15,000 volts, at which modulation takes place.

Modulator. Figure 10 gives a general view of the apparatus room with No. 2 set modulator at the extreme left.

The modulators used at KDKA for both 970 and 4,800-kc. units are duplicates, and while not arranged with transfer switches, can, in case of emergency, be cross-connected with jumpers to be used on either set.

The modulator units are designed to provide suitable modu-

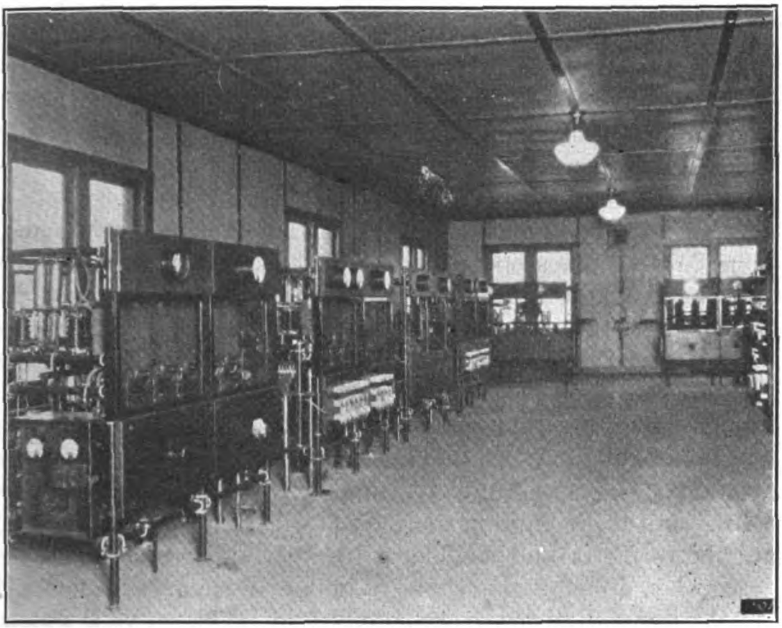

FIGURE 10—General View of Apparatus Room

lation for oscillators producing 40 kw. of radio frequency power input to the antenna.

Each modulator frame provides mounting for 12, type WO-41 tubes, arranged in pairs, the two tubes of each pair are supported on the same tube support plate, with their anodes electrically in parallel. A high-voltage disconnect switch that can be opened under load is provided for each pair, so that groups of tubes can be cut in or out, as desired. Each modulator tube grid lead is provided with a damping resistance, to prevent parasitic oscillations among the tubes. Under normal conditions, this grid lead resistance has no effect, as the modulator is not worked to where grid current is produced.

Bias or "C" battery voltage for the modulator tubes is provided by dry cell "B" batteries, housed in a box at the end of the frame. At the side of this box is an oil-insulated step-up transformer that supplies proper audio grid voltages for modulation. A milliammeter is provided in the main grid lead for indicating grid currents. It is used only as a check on test numbers, together with the modulation meter to determine the limits for modulation. A multi-point switch for adjusting bias voltages and a voltmeter for checking are also provided.

To insure a substantially uniform load for the modulator grid transformer, a resistance is connected across its high-voltage side. Without this, the load on the transformer would vary from approximately zero at low frequencies to an appreciable capacity reactance at the higher ones, thereby altering the effective transformer ratio, which is undesirable.

Normal operation at usual power adjustment employs nine, type WO-41 tubes operating in parallel. Characteristic curves of the modulator as a unit is shown in Figure 11. These are different from the ordinary grid voltage-plate voltage curves frequently used, but are plotted from the same data, and for this purpose are more convenient, as the curves are straight lines, which make interpolation easier.

Figure 12 shows the modulation characteristics of oscillator plate volts versus grid volts applied to the modulator. It is based on the assumption that constant current is being supplied to the oscillator and modulator together at all times, as is the case when a modulation choke of infinite inductance is connected in the common high-voltage supply lead. This curve is seen to be very nearly a straight line, and as such, indicates that the plate voltage variations impressed on the oscillator tubes are practically proportional to the voltage applied to the modulator grid. This is the condition necessary for the modulator to function with the minimum of distortion, and when considered in connection with the oscillator plate volts-antenna current curve, shows that the antenna current modulation will likewise be proportional to the applied modulator grid voltages, and reproduce its variation to a close degree.

Under normal conditions, the plate voltage is 9,000 and the bias 540 volts. Within the grid voltage limits of zero and twice 540 or 1,080, which must be observed if the station audio amplifier output is not to be distorted by the load of modulator grid currents, a variation of plate voltage from 2,500 to 15,000, giving

a modulation difference of 13,000 is obtainable. This variation corresponds $\frac{13,000}{2\times 9,000}$, or approximately 70 percent modulation.

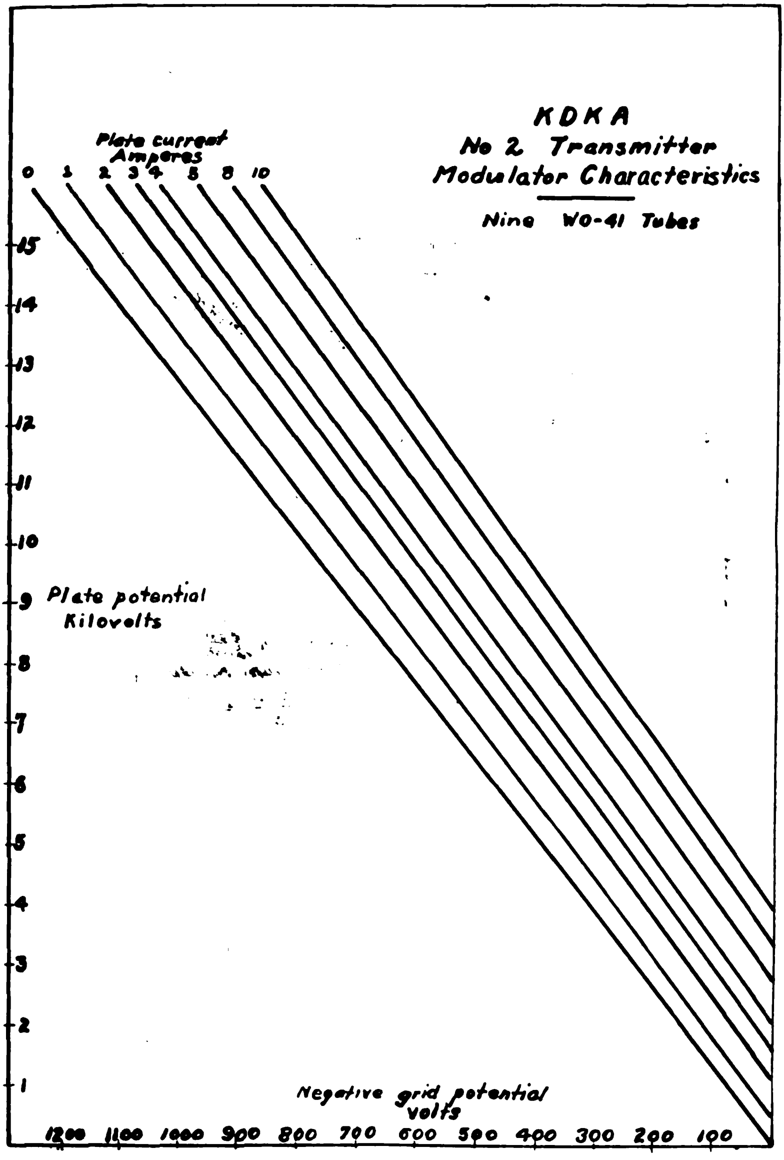

FIGURE 11—Modulator Characteristics, Static Curves

Oscillograms taken of rectifier antenna current bear out these deductions.

The amount of distortion over this range is of the order of 3 percent. This amount is ascertained by noting the departure of the curve from a straight line drawn as shown in Figure 12,

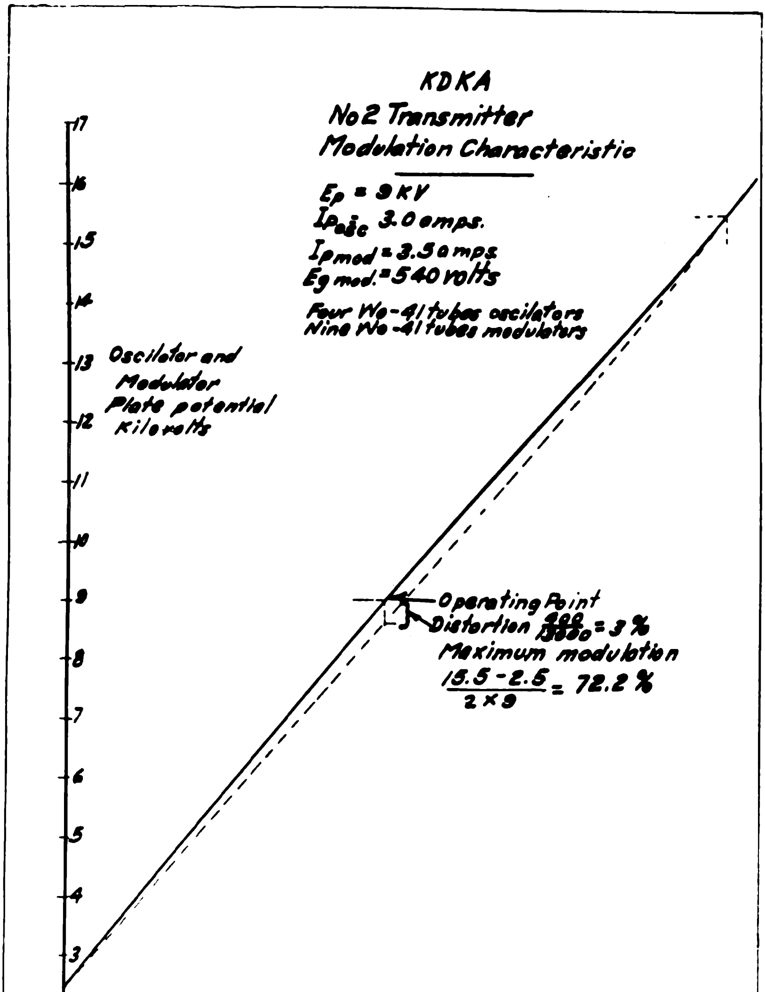

FIGURE 12—Modulator Characteristics, Operating Curve

and in this case, is found to be 400, or 3 percent of 13,000. Also, by plotting the differences, a double frequency curve is obtained,

which shows that the distortion is mostly a second harmonic. Because of its nature and small amount, distortion produced by the modulator, as adjusted, is entirely too small to be detected in any way, except by analytical measurements.

Another characteristic of the modulator that is quite important, is that of relative modulation plate voltage, available at the oscillator at different frequencies. When calculating the plate voltage-grid voltage modulation characteristic, it was assumed that there was no leakage in the modulation choke. Actually, this is not the case, particularly at low frequencies. For example, at 100 cycles, the reactance of a 10-henry choke is approximately 6,300 ohms. With the oscillator tubes to take three amperes at 9,000 volts, their average impedance is 3,000 ohms. This would look as if a considerable portion of modulation would be lost, as the modulation choke is practically in parallel to the ground across the oscillator tubes. However, the conditions are not nearly so bad as might seem at first thought, as the choke leakage is mainly at 90 degrees to the current passed into the oscillator, and the relatively low impedance of the modulator unit does not cause much voltage variation to take place, as the external impedance changes.

Considering the function of oscillator, modulation choke, and modulator units reveal that the audio voltage produced in the modulator acting as alternating current generator is impressed across an external impedance made up of the oscillator and modulation choke in parallel, as stated above. Therefore, the solution of elementary circuits, such as shown in Figure 13, will give the relative voltages available at the oscillator for different frequencies. The curves shown are those obtained using modulator impedance of 400 ohms, together with an oscillator impedance of 3,000 ohms, which, as before stated, are in normal conditions of operation. It will be noted that all curves tend to reach a maximum value of 88.2 percent at the higher frequencies. This is the limiting proportion of the voltage generated in the modulator by action of the grid potentials and amplification constants of the tubes that is available on the oscillator when the respective impedances are those stated. At low frequencies, when the choke reactance becomes comparatively low, thereby reducing the load impedance into which the modulator works, the relative available voltage falls below the maximum of 88.2 percent, in a manner shown by the curves. At KDKA, a 10-henry choke is used, and as seen from the curves, gives even at 25 cycles, about 84 percent volts available on the oscillator, which is rela-

tively 95 percent of the maximum available. Therefore, as far as the modulating system is concerned, the output is nearly constant over the full range of musical frequencies. Lack of choke, while not important, as far as speech and general phone trans-

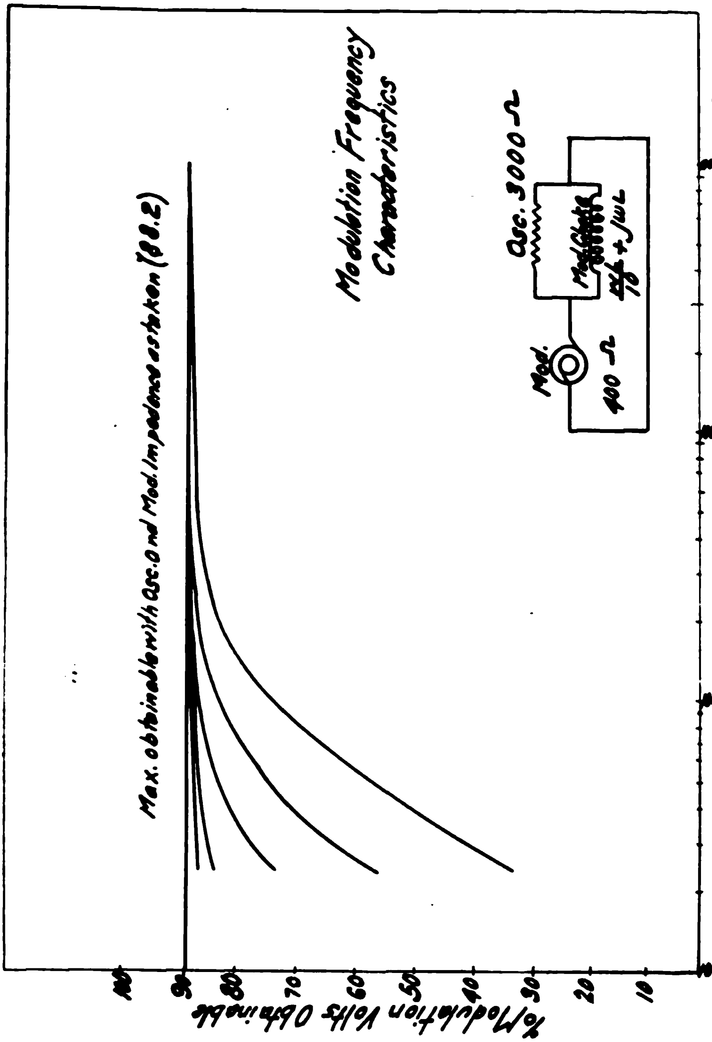

FIGURE 13—Modulator Characteristics, Frequency—Relative Plate Volts

mission is concerned, is not very noticeable, but to bring through the low notes that give the characteristic richness to pipe organ music, heavy choke is necessary, and special attention was given to this matter in constructing the apparatus for KDKA.

In calculating the modulation characteristics, one could not fail to be impressed by the way that low modulator impedance

is effective in eliminating distortion. In many cases, we are accustomed to think in terms of maximum output and balance of impedances, whereas, for good quality and minimum distortion, the main requirement is to have the modulator impedance low compared to its load. The latter is the general condition under which all ordinary power apparatus is normally operated. There is a striking parallel in this case to that of the early direct-current generator. It was at first thought that maximum output was important, and when loaded for this condition with external load resistance equal to the machine resistance, voltage regulation was found to be 50 percent and the efficiency correspondingly bad. Further consideration showed, however, that good efficiency and voltage regulation was obtainable by operating where the external load resistance was high compared to that of the machine, and modern machines are built to operate in this manner, although the output is much less than the maximum theoretically possible. Considering the modulator unit, the distortion was roughly comparable to the voltage regulation on the generator, and while actual power output efficiency is not important, the relative voltage output of the oscillator is; therefore, it is highly desirable to keep the modulator impedance low, in comparison to the load with which it is to work. Also, the curvature plate voltage, modulator-grid characteristic is produced by the change in average modulator impedance at different grid voltage amplitudes, and if the total impedance of the circuit is designed to be comprised mostly by the oscillators, which have substantially a constant impedance, the characteristic will be practically a straight line, with slight variations of modulator impedance having little effect. The same consideration applies equally to amplifiers, as a modulator as only a large power amplifier and in the audio equipment, as will be seen later, tubes in parallel are used to reduce the internal impedance, and not because large power output is required.

Audio Frequency Apparatus

Telephone lines from the various places of pick-up come to the telephone exchange works at East Pittsburgh, at which point the audio control is installed. Four lines connect this point with the station, a distance of approximately three miles. These lines terminate on the switchboard in the control room. Three complete station amplifiers are installed (shown in Figure 14). Any one of these may be connected with either broadcasting transmitter. The upper amplifiers (Nos. 1 and 2), have one 5-watt

balanced or push-ball stage and one 50-watt balanced stage. (See Figure 15 for diagram.) No. 3 is a single-side design, having two 5-watt tubes in parallel for the first stage and two 50-watt tubes in parallel for the second stage. This unit is impedance coupled, while the balanced units are transformer coupled. Characteristic curve of amplification, versus frequency, is given

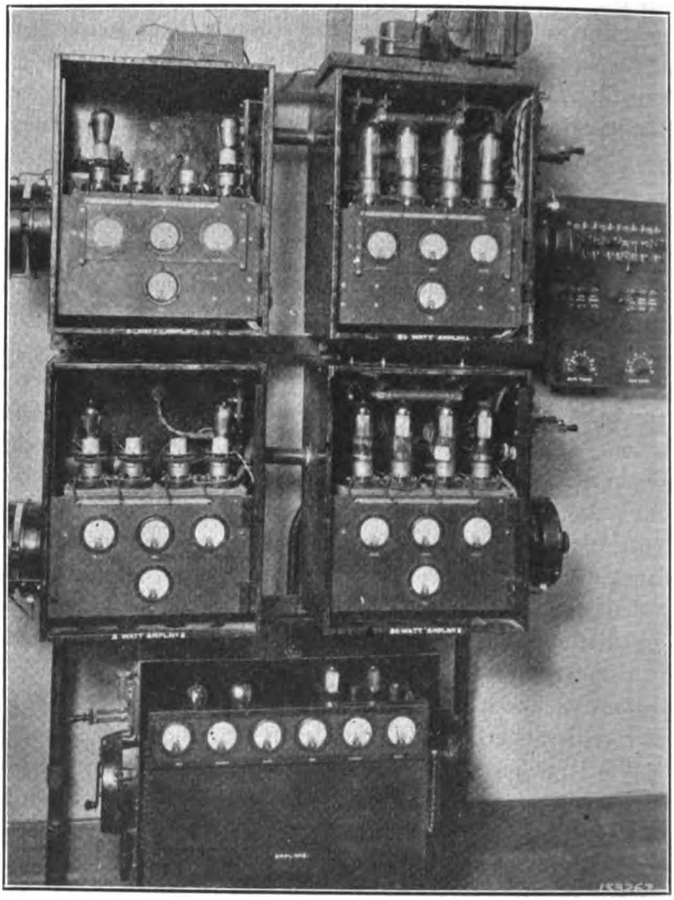

FIGURE 14—Audio Frequency Amplifier

in Figure 16. It will be seen that the amplification is substantially constant from 50 cycles to 1,000 cycles, after which the curve rises gradually to 6,000 cycles. The audio frequency thus amplified is stepped down to the line connecting the amplifiers and the modulator units.

Control of the amount of modulation is nominally in the

hands oi the man at the control position in the telephone exchange at East Pittsburgh Works. All line switching is handled from this point and potentiometers and filters are so arranged

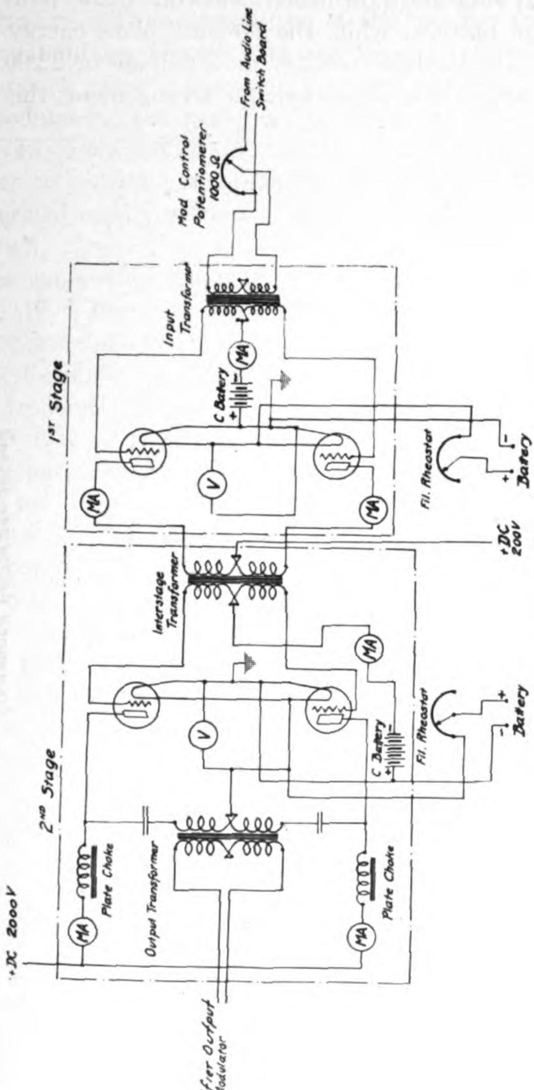

FIGURE 15—Amplifier Circuit Diagram

that by means of a vacuum-tube voltmeter the audio input to the station is held substantially constant at the proper level and line loss compensation is effected. In cases of emergency, the modulation can be controlled by potentiometer at the station

which is connected between the lines and the station amplifiers, as shown in diagram, Figure 15. The station amplifiers are furnished with filament power from a 12-volt storage battery, and the 5-watt stages are furnished 200-volt plate power also from a storage battery, while the 50-watt plate energy is obtained from a single-phase rectifier at a voltage of 2,200 direct current. By means of a potentiometer arrangement, this 2,200-

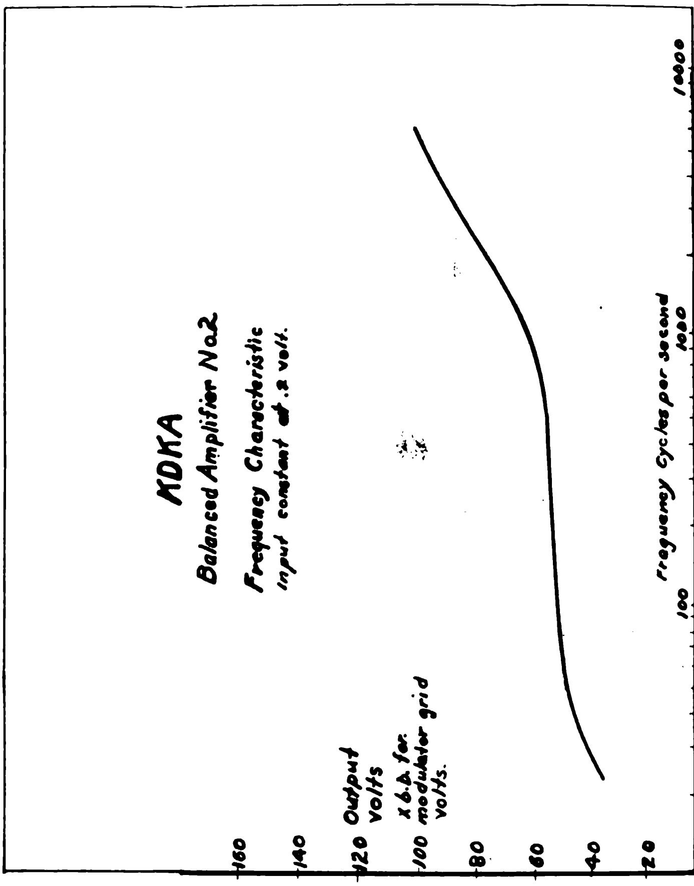

FIGURE 16—Amplifier Frequency Characteristic

volt direct current may also be used for the 5-watt stages, giving a net voltage of 350. Thoriated filament, 5- and 50-watt tubes are employed.

Rectifier. Hot cathode rectifiers are employed for high voltage direct current supply to the radio apparatus. There are three of these rectifiers as shown in the schematic diagram, Figure 2;

two are of the two-phase type, using twelve type WC-61 water-cooled tubes each, and are operated directly from the commercial 220-volt 3-phase 60-cycle power service. The output rating of each rectifier is 10,000 volts 12 ampere direct current, which is conservative. The construction of the rectifier frame is similar to the modulator frames with the tubes mounted in pairs, one pair to each phase. Disconnecting switches, similar to those on the modulators, are provided, by means of which any pair of tubes can be cut out in the case of trouble, thus permitting the rectifier to continue in operation at a slightly reduced output, its overload capacity being sufficient to continue normal in this condition.

The connection diagram of a rectifier and filter is shown in Figure 17. Three single-phase 220-volt to 22,000-volt transformers are employed for plate supply. This arrangement gives greater flexibility as regards replacement than if a single three-phase transformer were used. The direct-current output of the rectifier can be regulated in the 10 percent steps between 50 percent and 100 percent voltage through auto-transformers connected between the power service and the primary of the plate transformers. The high-voltage windings of the plate transformer are connected double star, thereby obtaining six-phase power. Neutral point of the star forms the negative terminal of the rectifier. The positive lead from the rectifier is taken directly off one of the filament busbars. Filament heating energy is obtained from one phase of the main supply, using a specially insulated transformer to give the proper filament voltage. The filament transformer is located in the basement and connected to the tubes through relatively long leads. The filament voltage is shown by a meter on the rectifier frame, the meter being insulated by means of a 1 to 1 voltage transformer. This arrangement is simple and more accurate than measuring voltage on the primary of the filament transformer or of providing a special winding on this transformer when low-voltage leads are long. No filament rheostat is used, as a power supply voltage regulation is good and the adjustment is not critical.

Owing to the exceedingly low resistance of the filaments when cold, which would result in the tubes drawing a heavy rush of current and possible damage if full voltage were applied when starting, a delayed action filament voltage relay is used, which acts to apply full voltage only after the tubes have become well heated by a limited current. The action of this relay is similar to the acceleration relay on a direct-current motor as

it speeds up, because of the change in voltage across the filament as the temperature rises.

To prevent voltage surges, sometimes caused by the rectifier

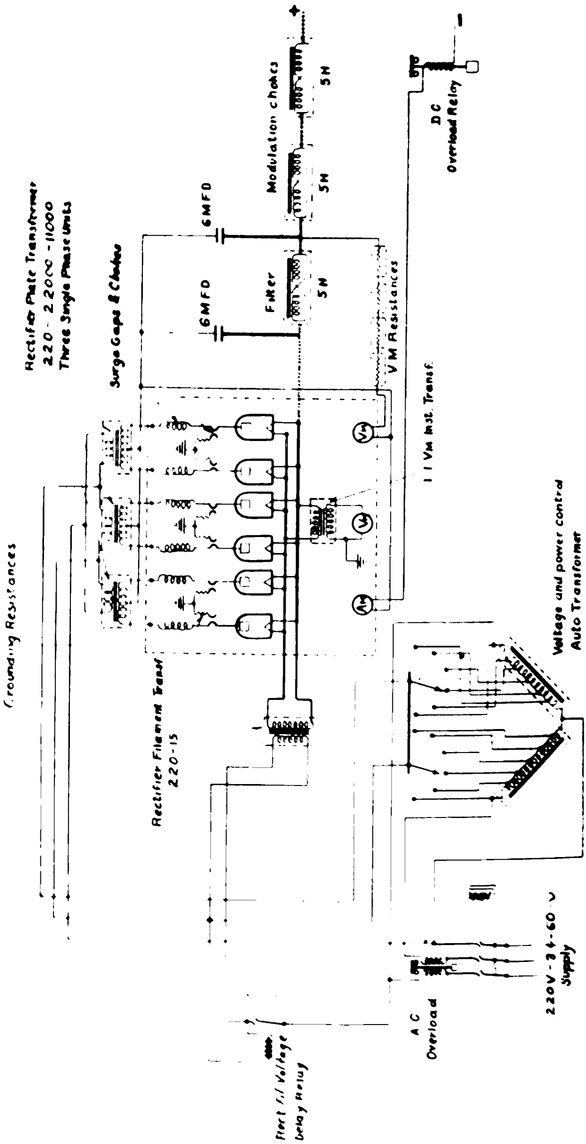

FIGURE 17—Circuit Diagram, Rectifier and Filter

tubes, from injuring the plate transformers, a surge gap and grounding resistor and choke are connected in each high-tension lead.

It has been found possible to conserve cooling water for the

rectifier tubes by passing it through three or four tubes in series, since the loss per tube is relatively small and gives only a moderate rise after passing through several tubes.

The filter used to smooth out the ripple left in the direct current from the rectifier, consists of a 5-henry choke coil and 12 μf. of condenser as shown in the diagram, Figure 17. This filter employs standard 10,000-volt condensers in one ½ μf. units which operate without balance resistors and their attendant losses. Figure 18 shows the filament modulator chokes and contactor panel.

The voltage ripple left at the output of the filter is so small that it cannot be seen on an oscillograph using a 3-inch deflec-

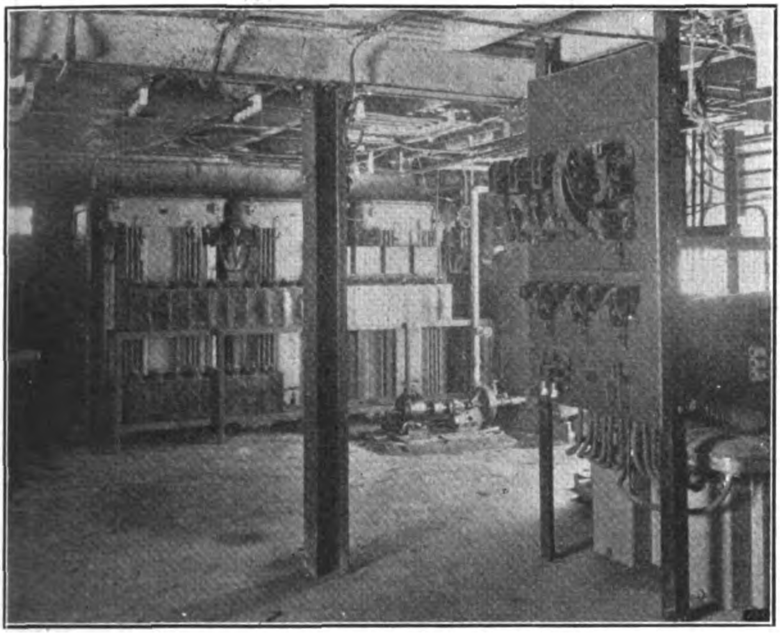

FIGURE 18—No. 2 Transmitter, Filter Control Panel

tion and is inaudible on the receivers used at the station. As a unit with the rectifier filter, and built in with it, is the modulation choke system, consisting of two 5-henry inductances which are duplicates of the filter choke.

Control. All of the apparatus may be controlled by means of push button and signal lights located in the control room, which is separated from the main apparatus room by a glass partition. Figure 19 shows the control desk. At the back of the

desk are the control buttons, signal lights, and modulation meters for transmitters Nos. 1 and 2, and buttons and lights for No. 3 transmitter. The audio frequency board, referred to previously, is at the left of the desk and includes a potentiometer for proper adjustment of audio input voltage. The chief operator, who is stationed at the desk, thus has complete control of power and audio circuits. The second operator is stationed

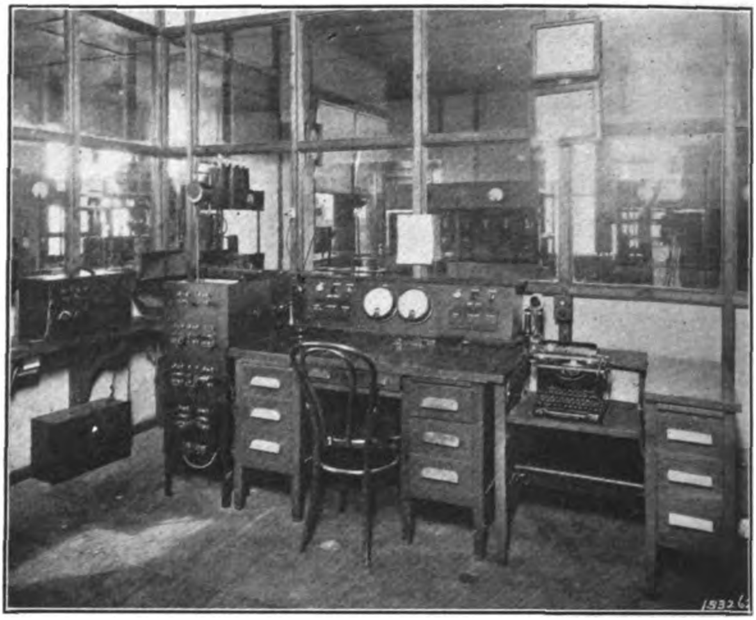

FIGURE 19—Control Desk

in the apparatus room and makes necessary adjustments of filaments, voltages, power output, wavelength, etc.

The power control is associated closely with the rectifier and operates in connection with it. The elementary diagram of the control system is shown in Figure 20. Relays are provided which give overload protection to both alternating-current and direct current-circuits and cut off the plate power in case the safe maximum is exceeded. Water pressure relays are used on all the tube frames, which interlock with the filament control relays and main power circuits to prevent any power being applied to the tubes until the water circulation is satisfactory. Relays are also provided on the modulator and oscillator, which prevent the application of plate power until the tube filaments are up to normal voltage. The push-button control and relays

are so interlocked that it is impossible to start filament and high-voltage in any way other than the proper sequence. In case the high-voltage-start button is operated, the filament will be brought up to the proper voltage and the high-voltage then applied automatically. Simultaneously, with starting the radio transmitter, the speech amplifier filament and plate supply may be connected so that the entire set can be placed in

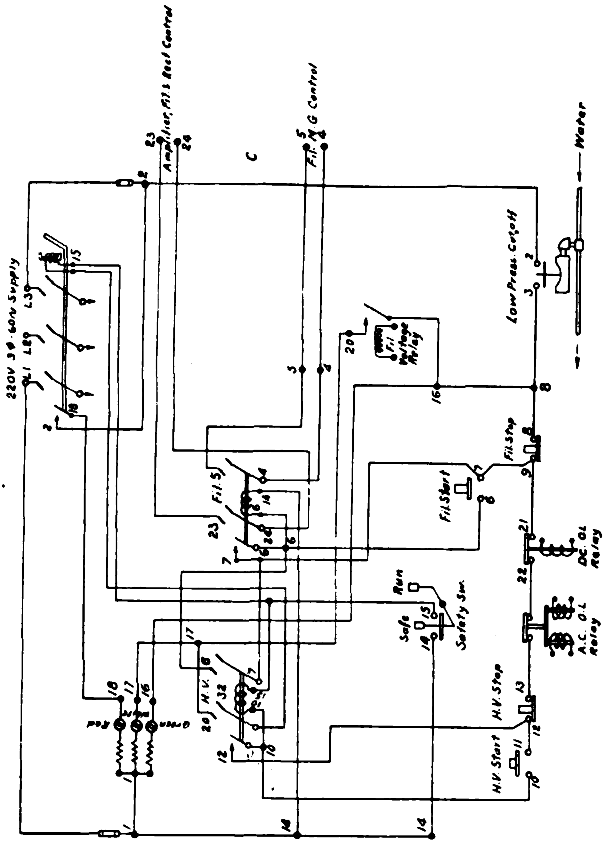

FIGURE 20—Circuit Control Diagram

operation by the pressing of one control button. Signal lights for each transmitter show when the cooling water is flowing, when the tube filaments are lighted and when the plate voltage is on. These lights are in the control room directly in front of the chief operator. Safety lock-out push buttons, which prevent application of high voltage, are provided on the tube frames for the use of the operators when making adjustments or repairs to the equipment.

Cooling water system is of the recirculation type, but no cooling tower is used. Cooling is effected by introducing fresh water into the circulation system as required to keep the temperature below the safe maximum. The supply water is very cold and only a relatively small amount is needed. The heat-dissipating ability of the system allows the operation of the set for a period of 30 to 45 minutes, without the use of outside cooling water. Two circulating pumps are provided, one of which is used as a spare part.

No. 3 Transmitter

No. 3 transmitter is employed for interworks telegraph service. Two WO-41 tubes are used as oscillators on either side

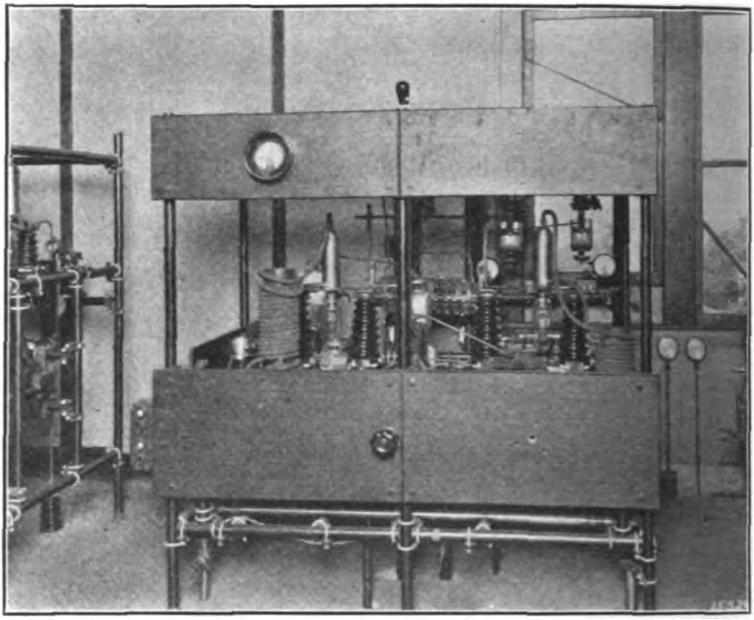

FIGURE 21—No. 3 Transmitter

of a push-pull circuit. The tubes work self-exciting into the primary oscillating circuit from which a short transmission line carries the power of 6 to 10 kw. to the antenna. Figure 21 shows the oscillator frame. Keying is ordinarily effected by means of compensated wave with a condenser type of relay. Straight keying by blocking with a holding bias, provided by a single tube rectifier, can also be used. Plate power is at 6,000 volts from a single-phase rectifier and filter, Figure 22.

No. 1 Transmitter

The transmitting apparatus, working on a frequency of 4,800 kc. (62.7 meters), is known as No. 1 set, as it was the first set installed in the building. Many changes have been made in this set since it was installed and put into operation last year.

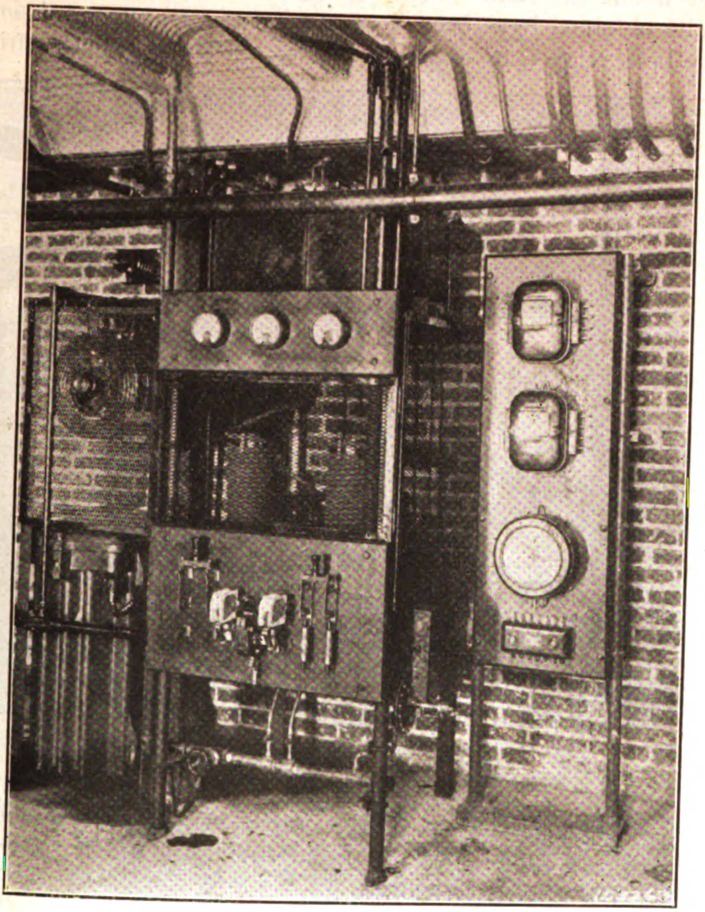

FIGURE 22—No. 3 Rectifier

The present arrangement utilizes one of the six-phase, 10,000-volt rectifiers described above. Modulation is by the constant current system. The radio-frequency apparatus is shown in Figure 23, and is of the quartz crystal controlled type. The crystal controls the frequency of a 5-watt tube and this is amplified through one 250-watt stage, one 500-watt balanced

stage, one 10-kw. balanced stage, and one 20-kw. balanced stage. Coupling to the antenna is by means of a short transmission line, the antenna itself being of the grid vertical conductor type. This crystal-controlled equipment may be the subject of a separate paper in the future and it is not thought advisable to say more about the radio-frequency apparatus at this time. The results obtained have been very gratifying. Our transmissions have been relayed in England, France, Germany, South Africa

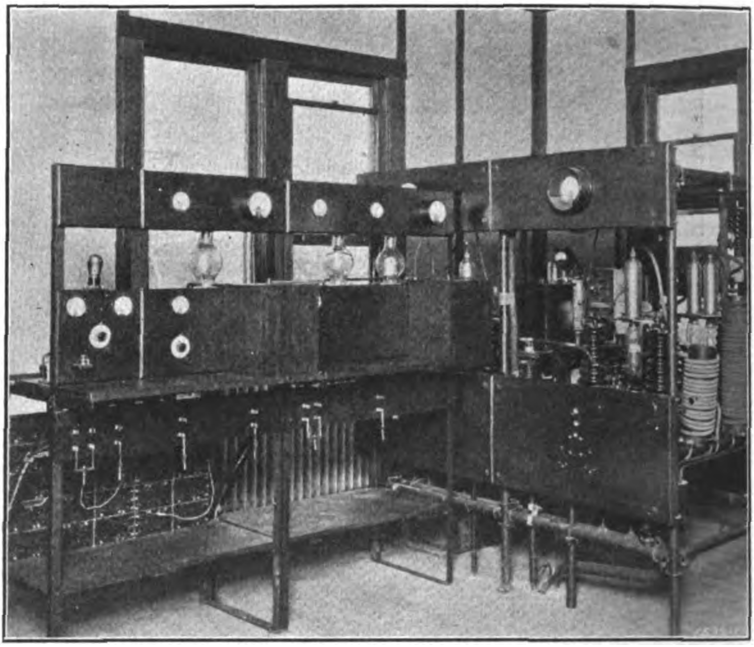

FIGURE 23—No. 1 Transmitter

and Australia. The use of the quartz crystal as a frequency stabilizer has gone a long way in improving the quality of transmission at short wave lengths.

CONCLUSION

It will be seen from the above description that, with the installation of duplicate equipment and switching arrangements made for the transfer of rectifiers, filament-generators, amplifiers, etc., from one set to another, failure from any cause is guarded against and continuity of service assured. Nothing has thus been spared in making KDKA a station that gives the best quality of broadcasting service.

A RADIO FIELD-STRENGTH MEASURING SYSTEM FOR FREQUENCIES UP TO FORTY MEGACYCLES*

By

H. T. Friis and E. Bruce

(Bell Telephone Laboratories, Inc.)

Introduction

There have been presented to the Institute descriptions of radio field strength measuring equipment which cover frequencies from the lowest in present usage up to and including the broadcast range.† This paper will deal with a new system of measurement which has been used successfully at a frequency as high as forty megacycles. While this frequency has been the extent of our endeavor, it is our belief that the fundamental principles can be employed at still higher frequencies when the occasion demands.

Prior Systems

Previously, the most satisfactory method of radio signal measurement consisted of the substitution, for the received signal, of a known locally-generated e.m.f. at the loop center, identical in frequency to the signal, and of such magnitude as to produce the same receiver output as that resulting from the received signal. Under these simulated conditions, the known locally-generated e.m.f. is equal to the voltage induced in the loop by the signal. The field strength is obtained by dividing this induced voltage by the effective height‡ of the loop.

The magnitude of the locally-generated e.m.f. is usually obtained by passing a known current through a known impedance inserted at the loop center. It is desirable that this known impedance be a pure resistance in order to establish its independence of frequency, also its value should be kept as small

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†"Note on the Measurement of Radio Signals," C. R. Englund, Proceedings of The Institute of Radio Engineers, February, 1923.

"Radio Transmission Measurements," R. Bown, C. R. Englund, and H. T. Friis, Proceedings of The Institute of Radio Engineers, April, 1923.

"Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies," A. G. Jensen, presented before The Institute of Radio Engineers, New York, April 7, 1926.

‡The effective height of a loop is defined as the height of an equivalent vertical wire, having the same induced voltage.

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... High Frequencies

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Fundamentals of Proposed System

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Furthermore, the search for an appropriate location for the voltage attenuator, beyond the loop, revealed the desirability of placing it on the output of the intermediate-frequency detector of a double-detection scheme, with due regard for the limits of overloading of this tube. The importance of this arrangement should be emphasized. It means that the attenuator need operate at only the fixed intermediate frequency. Since this frequency has been selected as 300 kilocycles, great accuracy is possible without elaborate attenuator design, regardless of the signal frequency.

As an illustration, Figure 1 will be of assistance in explaining how these principles may be employed in the measurement of some unknown voltage occurring at a high frequency.

The intermediate frequency detector also serves as a tube voltmeter actuating the d.c. plate circuit meter A_1 shown in the

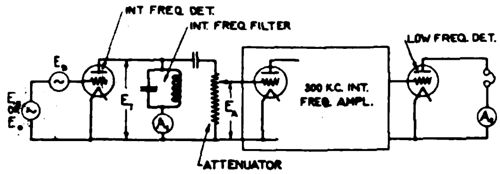

FIGURE 1—Voltage Measurement Apparatus

sketch. The gain control or voltage attenuator is calibrated directly in voltage ratios; thus a reading of 10,000 indicates that the input voltage to the attenuator is 10,000 times larger than the output voltage.

From the modulation theory, it is known that

$$E_I = k\,E_X\,E_B \tag{1}$$

below the overloading limits of the intermediate frequency detector.

Applying the unknown voltage E_X at a frequency f, the frequency of E_B is adjusted to be $f \pm 300$ kc. The attenuator is then regulated until a convenient deflection appears on A_2. Assume this attenuation to be a_1. Then we can write

$$E_A = \frac{k\,E_X\,E_B}{a_1} \tag{2}$$

Suppose we substitute for E_X a voltage E_o, identical in frequency, but sufficiently large to be measurable when using the intermediate detector as a tube voltmeter (E_B turned off). With E_B the same as in (2), the attenuator is readjusted to a_2 where A_2 again reads the same as before. Under these conditions E_A must also be the same as previously. Now

$$E_A = \frac{k\,E_O\,E_B}{a_2} \tag{3}$$

Equating (2) and (3)

$$\frac{k\,E_X\,E_B}{a_1} = \frac{k\,E_O\,E_B}{a_2} \quad \text{or}$$

$$E_X = E_O\frac{a_1}{a_2} \quad \text{which is the desired equality.} \tag{4}$$

as is practical. The minute, known currents are obtained by attenuating measurable currents by known amounts through the use of suitable networks. It is evident that the local oscillator and the attenuating network must be separately and thoroughly shielded from the loop or failure will result.

Difficulties at High Frequencies

As the frequency is increased, the proper construction of the described system becomes more difficult. Unless great ingenuity and extreme caution are exercised, inaccuracies creep into the attenuating networks, due to reactive effects, as well as into the resistance at the loop center. The problem of shielding at very high frequencies becomes considerable by reason of the low field strength values at which high-frequency communication is possible. Since the problem of the authors was to design apparatus for the measurement of signals at frequencies as high as twenty-five times the upper frequency limit of apparatus then available, the economic aspect eliminated existing systems from consideration.

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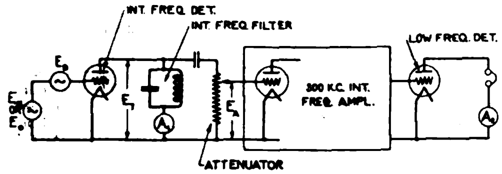

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We can extend these manipulative operations to the measurement of a radio signal by means of the apparatus shown in Figure 2A. These operations are tabulated below.

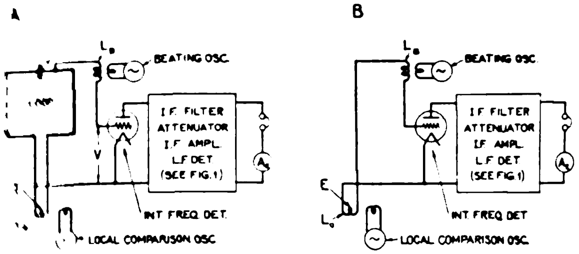

FIGURE 2—Field Strength Measurement Apparatus

TABLE OF PROCEDURE

		Attenuation Ratio of Attenuator
I	The receiving set is tuned to the incoming signal. The attenuator is adjusted until a convenient output deflection is obtained. This deflection is noted.	a_1
II	(1) The local comparison oscillator is started and tuned to resonance with the receiving set.	
	(2) The attenuator is adjusted to make the output the same as in I.	a_2
	(3) The input V to the grid of the intermediate frequency detector is determined (beating oscillator is off during this measurement).	
III	(1) The grid of the intermediate frequency detector is connected through L_B to the local oscillator input as shown in Figure 2B.	
	(2) The attenuator is readjusted to make output the same as in case I.	a_3

From this table we have

Voltage across half of the loop due to incoming signal $= \dfrac{V}{\frac{a_2}{a_1}}$ volts

Loop voltage step-up (the ratio of half of the loop terminal voltage to the induced voltage) $= \beta = \dfrac{a_2}{a_3}$

Voltage induced in loop by comparison oscillator $= E = \dfrac{V}{\beta}$ volts

Voltage induced into loop by incoming signal $= \dfrac{V}{\frac{a_2}{a_1}\beta}$ volts.

It should be noted here that it is entirely unnecessary for the transmitter of the incoming signal to stop while measurements are being made.

Detailed Discussion

With this explanation of the fundamental principles underlying the proposed system, some refinements in the accurate measurement of the voltage step-up β of the loop may well be discussed.

Figure 2A illustrates the usual arrangement for obtaining the beating oscillator input in double-detection sets and the ratio of attenuations $\frac{a_2}{a_3}$ (as of the previous table) should normally give the effective loop step-up. Unfortunately, however, such a procedure leads to a large error due to a large change in beating oscillator input to the intermediate-frequency detector, as the change is made from connections 2A to 2B. Also a small error due to the voltage drop across L_B is present.

In Figure 2A, the loop resonance frequency differs from the beating oscillator frequency only by the value of the intermediate frequency. At short waves, this proximity is usually very close in percentage. The removal of the loop circuit, Figure 2B, therefore greatly affects the beating oscillator input due to the radical change in the character of the load on the beating oscillator.

Figure 3A shows a balanced beating oscillator input system where the input from the beating oscillator is independent of loop tune. Changing the connections to those of Figure 3B

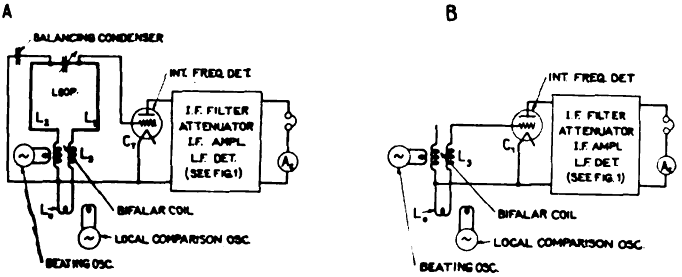

FIGURE 3—Balanced Beating Oscillator Input Circuit

gives the loop step-up fairly accurately. However, this measurement is still slightly in error but is a great improvement on the method in Figure 2. This error results from the removal of L_1 from the circuit $L_o-L_3-L_1-C_T$ through which the current, induced by the beating oscillator, circulates. Since the impedance of L_1 is small compared to that of C_T, the error resulting from the removal of L_1 is small but increases in magnitude at

shorter wave-lengths. The voltage drop across L_3 is still responsible for a small error.

Figure 4 shows the methods finally adopted and Figures 5 and 6 are photographs of a measurement set employing this

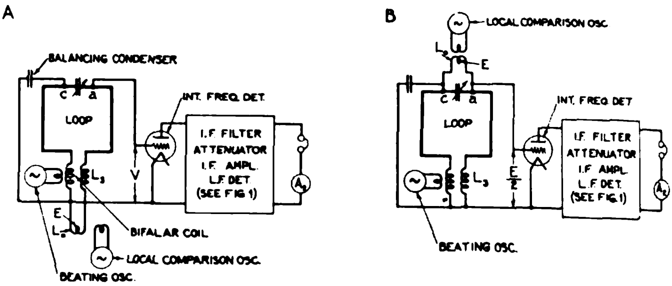

FIGURE 4—Circuit Finally Adopted of Field Strength Measurement Apparatus Employing Grid Modulation

scheme. The local signal voltage impressed on the tube input in Figure 4A is very close to half the loop terminal voltage. (V is over 100 times E and nearly at right angles vectorally).

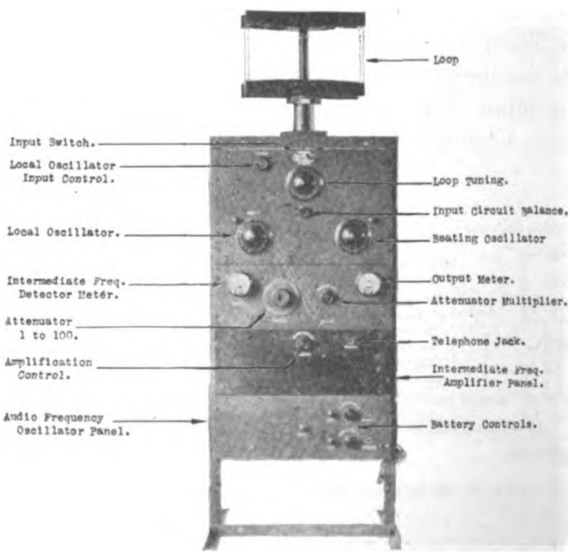

FIGURE 5—Field Strength Measurement Apparatus Employing Grid Modulation

In Figure 4B the coil L_o has been connected across points *ac*. No change in the beating oscillator input occurs from this change in connections, since there is no potential difference between *a* and *c* in respect to the beating oscillator. The im-

pedance of the coil L_o is very small compared with the impedance between points a and c. Therefore the voltage impressed on the tube input by virtue of E is $\frac{E}{2}$. By this method we measure the ratio

$$\frac{V}{\frac{E}{2}} = 2\beta = \text{twice the loop step-up.}$$

This method has been carefully checked by calculation of the loop step-up from the measured frequency characteristic of the loop circuit. These checks have been very satisfactory.

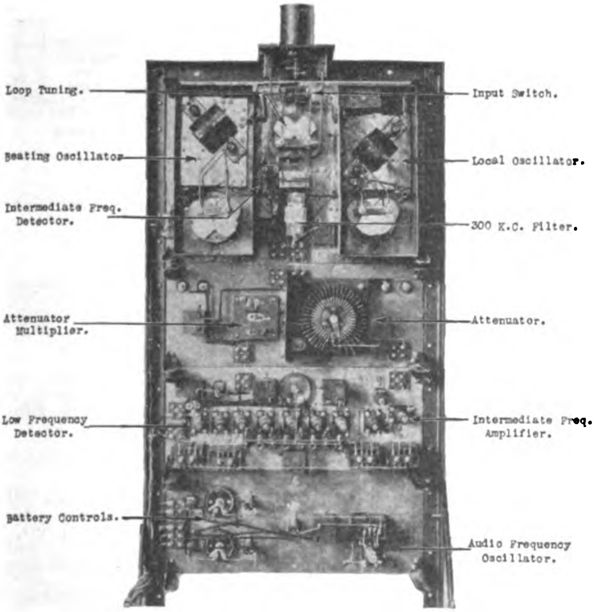

FIGURE 6—Same as Figure 5, with Copper Shielding Boxes Removed

It might be mentioned that possible errors in practice due to spurious capacities to ground do not occur because of the small impedance of the source E. Also it is not absolutely necessary that the loop circuit be accurately anti-resonant in Figure 4B since the loop impedance is large compared with that of L_o.

Figure 7 illustrates the application of the method of measurement in the case of plate modulation of the beating oscillator input. The introduction of the beating oscillator in the plate circuit of the intermediate frequency detector is important be-

cause it makes possible the simplification of the input circuit. Balancing is provided so that no appreciable voltage from the beating oscillator appears between the grid and filament of the intermediate frequency detector. Under these conditions changes in the input circuit impedance do not react on the beating oscillator. Here again the use of the anti-resonant circuit in Figure 7B prevents errors due to the low impedance of the grid to filament capacity of the intermediate frequency detector at high frequencies. A measuring set has been constructed

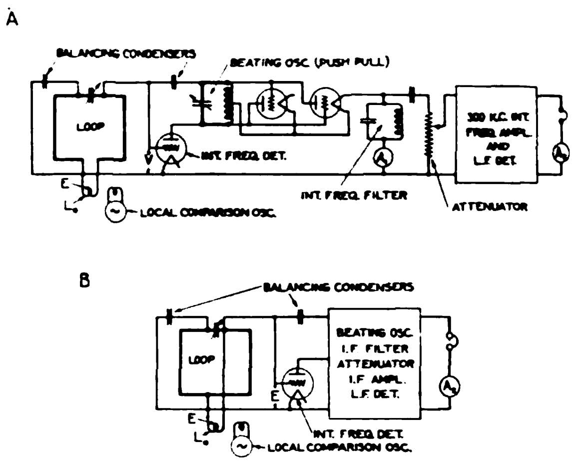

FIGURE 7—Field Strength Measurement Apparatus Employing Plate Modulation—Loop Antenna

employing the plate modulation scheme. This is illustrated by photographic reproductions in Figures 8, 9 and 10.

Since the input circuit for the plate modulation requires no balanced circuits, as does the grid modulation scheme, this system is particularly applicable for operation in conjunction with antenna systems as shown in Figure 11. This provides a means of increasing the sensitivity of the set. It of course is necessary to know the effective height of the signal collector of measuring sets and this can be calculated quite accurately in the case of a loop. When antennas are used, their effective height can be obtained in terms of a known loop by direct comparison, using a small portable oscillator placed ten or more wave-lengths away from the antenna.

This system of measurement is naturally wholly dependent on the calibration of the intermediate frequency detector as a tube voltmeter and the independence of this calibration as to

frequency. Direct laboratory measurement has demonstrated this independence for frequencies varying from 60 up to 2,000,000 cycles per second. At higher frequencies, laboratory checks are difficult due to an absence of a suitable standard of comparison. There does not seem to be any reason to believe that the calibration does not hold up to possibly 50 megacycles. It has

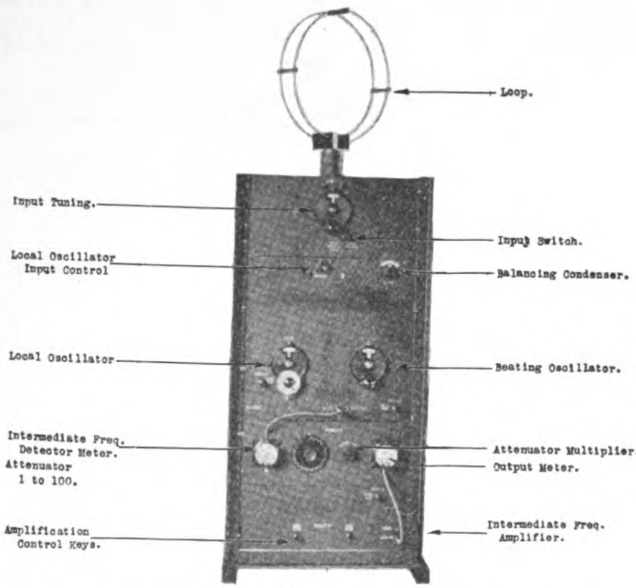

FIGURE 8—Field Strength Measurement Apparatus Employing Plate Modulation

always been found most convenient to calibrate the tube voltmeter at 60 cycles per second.

The statement has been made in connection with Figure 1 that

$$E_I = k\, E_X\, E_B$$

for the intermediate-frequency detector within the limits of overloading. By overloading we mean the region where k is no longer constant. Careful tests have shown that k does not change beyond the limits of tolerance as E_X is varied from 2 volts down to 2×10^{-5} volts, at a frequency of one megacycle, where it is still possible to construct potentiometers of sufficient accuracy.

Circumstantial evidence as to the accuracy of this action at high frequencies is given by the fact that when E_X and E_B at

about 40 megacycles are made the same as E_X and E_B at about one megacycle, as indicated by the intermediate frequency detector as a tube voltmeter, the factor k is identical in both cases.

The gain control or attenuator is made of resistance units wound non-inductively (reversed loop) on a thin card. An

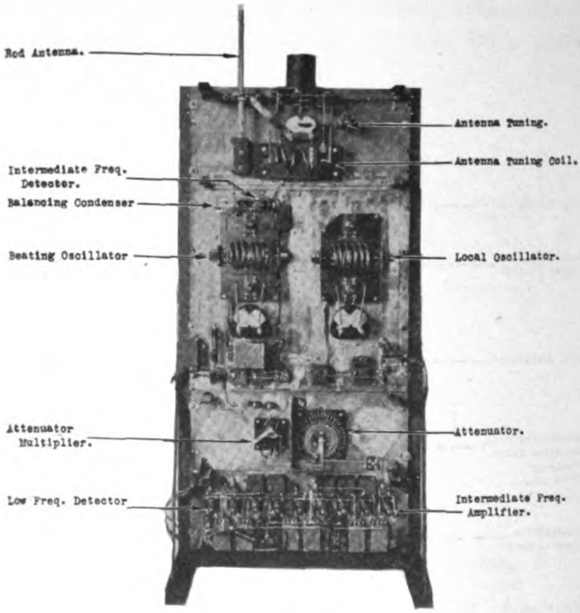

FIGURE 9—Apparatus Employing Plate Modulation with Copper Shielding Boxes Removed

idea of this construction can best be obtained by examining the photographs. Maximum attenuation is 10^{-6} times.

The intermediate frequency amplifier is of fairly standard construction. Its resonant frequency is 300 kilocycles and the band width has been adjusted to about 30 kilocycles. This broad band eliminates "hair line" tuning at the higher signal frequencies.

In regard to the sensitivity of the set, it should be recalled that the voltage induced into the loop by the incoming signal is given by

$$\frac{V}{\frac{a_2}{a_1}\beta}.$$

The field strength in microvolts per meter of the received signal is therefore

$$\frac{\mu v}{m} = \frac{V \times 10^8}{\frac{a_2}{a_1} \beta H}$$

where H is the effective height of the signal collector in centimeters. V is usually chosen as one volt for convenience.

The largest ratio of $\frac{a_2}{a_1}$ is determined by the total amplification of the set and the sensitivity of the output indicator.* For the sets in the photographs, this ratio is close to 5×10^4. The

FIGURE 10 — Field Strength Measurement Apparatus Employing Plate Modulation

loop voltage step-up ratio β depends on the construction of the loop. Examples of this ratio are given in the following Table II. These values are for the four-turn loop and the two-turn loop shown respectively in Figures 10 and 8. Assuming that the average product of the loop step-up and effective height is about 500 (see Table II), the minimum field strength measurable when using these loops is about

* A Western Electric "N" Tube (215-A), Plate Curvature, Tube Voltmeter.

$$\varepsilon = \frac{1 x 10^8}{50{,}000 \times 500} = 4 \frac{\mu V}{m}.$$

TABLE II

Turns	Diameter	Frequency	• Loop Voltage Step-up β	$\frac{\omega L}{R}$	H cms.	$\beta x H$
4	44.2 cm.	4.9 x 10^6	120	240	6.3	760
4	44.2 cm.	7.8 x 10^6	75	150	10	750
2	35 cm.	8.6 x 10^6	80	160	3.5	280
2	35 cm.	17 x 10^6	60	120	6.8	410

Using an open vertical antenna, constructed of ½ inch copper pipe, as a signal collector, instead of a loop, the set sensitivity can be multiplied from 5 to 10 times. Table III, below, gives

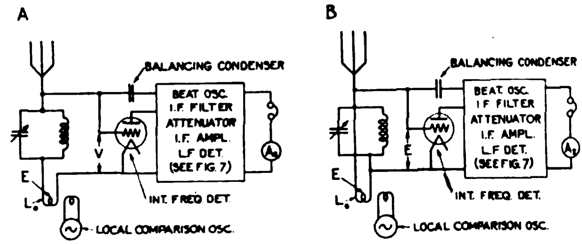

FIGURE 11—Field Strength Measurement Apparatus Employing Plate Modulation—Open Antenna

examples of comparison data on various lengths of pipe, their measured effective heights, and their effectiveness as signal collectors as compared with the previously mentioned loops. In most cases, these antennas make possible the measurement of fractional parts of a microvolt per meter.

TABLE III

Antenna	Signal Strength $\eta v/m$	Frequency	H_{ef} cm.	Relative values of Antenna Outputs
4-turn loop............	455	5.4 x 10^6	6.9	1
Rod 80 cm. long.......	455	5.4 x 10^6	22	4.6
Rod 231 cm. long.......	455	5.4 x 10^6	80	5
Rod 427 cm. long.......	455	5.4 x 10^6	152	7.6
2-turn loop............	1260	16.1 x 10^6	6.5	1
Rod 80 cm. long.......	1260	16.1 x 10^6	2.5	5.4
Rod 231 cm. long.......	1260	16.1 x 10^6	105	4.5
Rod 427 cm. long.......	1260	16.1 x 10^6		below 1
Rod 10 cm. long.......	900	30 x 10^6		below 1
Rod 50 cm. long.......	900	30 x 10^6		2.6
Rod 80 cm. long.......	900	30 x 10^6		2.6
Rod 150 cm. long.......	900	30 x 10^6		1

It is interesting to note the existence of optimum lengths of these antennas at a given signal frequency. This is due to the

fact that the radiation resistance increases as the square of the effective height while the induced voltage is only proportional to it. Simple calculations show that an optimum value is obtained when the radiation resistance is equal to the circuit resistance.

The frequency range of the set utilizing plate modulation is from 0.7 to 20 megacycles using a loop antenna. With the open vertical antenna the upper limit is raised to 43 megacycles. This large frequency range is made possible by the use of a set of interchangeable oscillator coils, loops, antennas and tuning coils.

In conclusion, it may be well to enumerate the major factors which make this system of short wave measurement possible.

1. The method facilitates the shielding of the local signal oscillator.

2. All the required known attenuations are made at a relatively low and fixed intermediate frequency.

3. The comparison voltage is measured directly by means of a tube voltmeter. This method is more satisfactory than the current-impedance drop method at the very high frequencies.

4. Effective balancing circuits have been devised whereby the input circuits to the intermediate frequency detector do not react upon the beating oscillator input.

5. The completed system is capable of giving the absolute field strength of a received signal within 20 per cent of its true value. Comparative signal measurements can be made with an error of not more than 5 per cent. The prevalence of fading at the high frequencies make these degrees of accuracy quite ample.

SUMMARY: The paper describes field strength measurement sets for frequencies as high as forty megacycles. The apparatus is a double detection receiving set which is equipped with a calibrated intermediate frequency attenuator and a local signal comparison oscillator. The local signal is measured by means of the intermediate frequency detector which is calibrated as a tube voltmeter.

RELATION BETWEEN THE HEIGHT OF THE KENNELLY-HEAVISIDE LAYER AND HIGH FREQUENCY RADIO TRANSMISSION PHENOMENA*

By

A. Hoyt Taylor

The theoretical basis of this paper has been published in the "Physical Review" for January, 1926.[1] The paper referred to was in turn based upon certain experimental data[2] which have been considerably extended since the date of submitting the same for publication.

The present discussion concerns itself solely with waves short enough to show the skip distance effect and one of its main interests lies perhaps in the indication that it may give as to the possible lower limit of wavelength which will be useful in long-distance communication. In reference (1), it has been shown that for the period covered by the data in reference (2) the average height of the Kennelly-Heaviside layer during the daylight hours was 150 miles reduced to the basis of the height of an equivalent reflector. It must be kept in mind, however, that the actual process is not one of reflection. At the same time, fortunately, methods of graphic representation of high-frequency phenomena may be employed based upon an equivalent reflection without introducing any inaccuracy, except that it is important to recognize that the full treatment on the refraction basis is such that in the general case there are four rays coming down after refraction from the layer; two of them being plane polarized and two circularly polarized; and these four rays need not, indeed usually are not, coherent. For the sake of simplicity, the following discussion will be based on a single ray, taking the one which has the smallest refractive index. This means the ray which will first reach the earth after refraction (reflection from layer at equivalent height). In reference (1), for 150-mile layer, it was shown that the shortest wave it would be possible to use in long distance communication would be 14 meters. Extensive

*Received by the Editor, April 29, 1926.

[1] Hulburt and Taylor, "Physical Review," Feb., 1926.

[2] Taylor, Proceedings of The Institute of Radio Engineers, December, 1925.

experiments have not brought forth any evidence contradicting this conclusion, but inasmuch as the Heaviside layer during the middle of the day is lower than at other portions of the day, and is in fact lower in summer than it is in winter, it has been thought worth while to extend the investigations to the study of transmissions between 11 and 20 meters, carried out over long distance in the middle of the day. The results of these transmission studies have shown a very gratifying agreement with earlier work and have permitted some calculations on the height of the layer at various times, which permit to a certain extent, the forecasting of probable results to be obtained at various wavelengths, provided those wavelengths are short enough to show skip distance effects. Practically, this means waves somewhat shorter than 60 meters. The inclusion of the three other waves with different states of polarization and other refractive indices will not in any way change the character of the general results, but will merely serve somewhat to blur or obscure the otherwise sharp boundary between zones of reception and non-reception.

Figure 1 shows the state of affairs when transmitting station S is able to transmit rays at all angles between the vertical and horizontal. The horizontal ray, which can only be transmitted if the station is elevated a considerable distance off the ground (otherwise it would be absorbed) is, afterrefraction (equivalent refraction) from the layer, brought down at a considerable distance from the transmitter. Let the angle of the ray with the horizontal ray be α. The radius of the earth is designated by the latter R, and the height of the layer by h. Let α' be the ray of the highest angle, which can be used and still return to the earth. The line $R+h$ is drawn from the center of the earth to the point on the layer which is struck by this ray. This ray returns to the earth at an angular distance of $\theta°$ from the transmitter S. This angle to $\theta°$ corresponds to the skip distance, that is, $D=2\theta \times 69.8$. What actually happens is that all rays at a higher angle than α, if the wave is short enough, are not sufficiently refracted ever to return to the earth, or, putting it on the equivalent reflection basis, we may say that since we exceed the critical angle, thay will not be reflected. It must be kept in mind that the velocity within the layer is higher than the velocity in free space, due to the presence of electrons within the layer. The angle β is the critical angle. It the ray strikes the layer in such a way as to exceed the critical value of β (which is, of course, a function of the frequency), the ray will not return. This is the physical meaning of the skip distance. It will be seen that for

a layer of uniform height, a simple relation exists between β, θ, α', h, R and μ, the refractive index, where α' is the value of α, corresponding to the critical value of β. This relation is

$$\cos(\alpha'+\theta)=\frac{R}{R+h}\cos\alpha'=\sin\beta=\mu.$$

The curve of the refractive indices is shown in Figure 2, the values being calculated as previously in reference (1), using the ray with the smallest refractive index. Knowing the value of

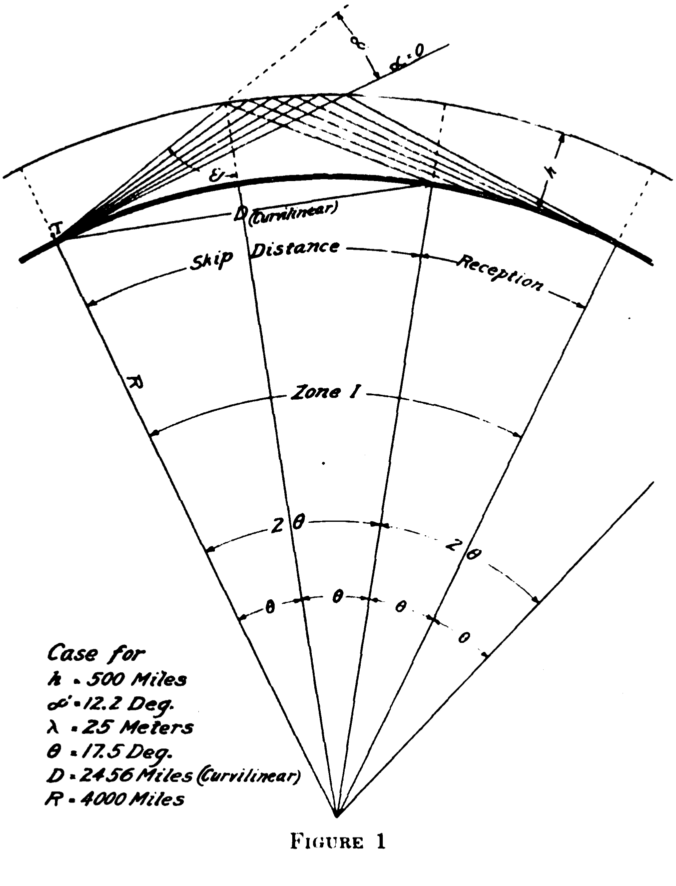

FIGURE 1

the refractive index for any wave, we are in a position to compute the critical value of α, which may be used; in other words, the radiation of the highest angle which is useful in producing a return wave from the sky. Further we can compute the width of the zone of reception for any given cone of emitted rays. If, for instance, the upper limit of our cone is the critical angle, α', and the lower limit is the small angle α, which in the limiting

case is 0 (ray horizontal), there will be two values of θ, where θ' corresponds to α' and θ corresponds to α. α' is greater than α, but θ' is less than θ. The breadth of the first zone of reception

$$B=\frac{4\pi R}{360}(\theta-\theta').$$

In general, if B_n is the breadth of the nth zone of reception, then

$$B_n=\frac{4\pi Rn}{360}(\theta-\theta').$$

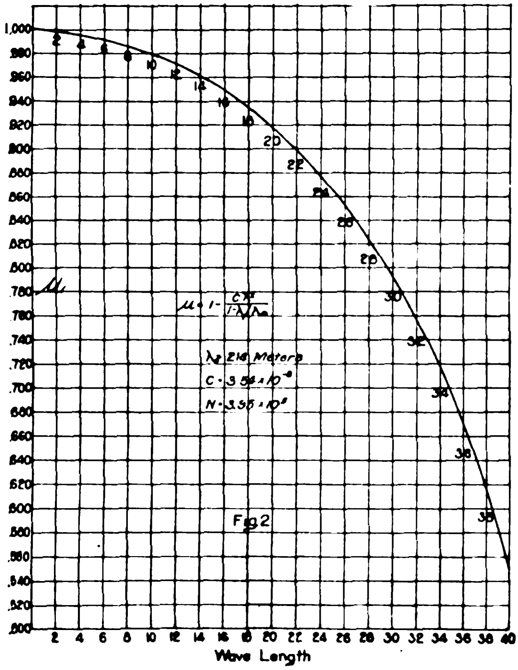

FIGURE 2

The next zone beyond n will have the breadth

$$B_{n+1}=\frac{4\pi R}{360^\circ}(n+1)(\theta-\theta')$$

This is assuming that θ is measured in degrees. The gap or zone of non-reception, lying between any two zones is from the advanced edge of zone n to the rear edge of zone $n+1$, which is

$$G_n=\frac{4\pi R}{360}[(n+1)\theta'-n\,\theta]$$

There will be no gaps when this expression is negative; that is, when $n\,\theta \geqq (n+1)\theta'$, or $n \geqq \dfrac{\theta'}{\theta-\theta'}$.

The following illustrations will show this works out. Case 1—Suppose our cone of rays is limited between the horizontal ray and 10°. θ then is equal to 15° 27′ and θ' is equal to 8°, 20′. The application of the preceding criterion for the existence of gaps shows that a gap does occur between zone 1 and zone 2, and that the gap is nearer zone 1 than it is to zone 2. Case 2—A cone of rays limited between the horizontal and 15°. If this case is calculated we find that θ equals 15°, 27′, θ' equals 6°, 24′, and the application of the criterion for gaps shows that there are no gaps after the first skip distance; that is, there are no gaps in reception following zone 1, but if the nearness of the transmitter to the ground should so absorb the lower rays that our cone is limited between 5° and 10°, the calculation shows that θ will equal 11°, 13′, θ' equals 8°, 20′, and the application of the criterion indicates that the gaps do not disappear until the region of reception is beyond the second zone. The criterion will also show that there is grave danger in the neighborhood of the outer edge of zone 3, since the conditions for no gaps are barely met and a very little variation in the height of the layer will introduce a gap. A limiting case for extremely short waves is where the refractive index is equal to unity. This would give

$$\cos \alpha' = \frac{R+h}{R}$$

This, of course, can only be true if $h=0$; in other words, unless the layer is extremely low down, extremely short waves cannot be used effectively over distances of more than a few miles. It is interesting to see whether these results can be expressed graphically in such a way as to approximate the actual distance of long distance transmission.

Figure A depicts the pattern produced on the earth by different zones of reception and non-reception when there are three different conditions for a Heaviside layer height of 150 miles, and two different wave lengths, which show an initial skip distance of 500 and 1,500 miles, respectively. The figure is drawn to scale and assumes a uniform layer. The transmitter is at W. The ray at the critical angle for the wavelength of 500-mile skip distance is drawn as a solid line. The ray at the critical angle for the wave, which shows the 1,500-mile skip is represented by long dashes separated by a single dot. The horizontal or

FIGURE A

tangent ray is represented by long dashes separated by two dots, and the ray for which $\alpha = 3°$, that is, 3° above the horizontal, is represented by short dashes.

Case 1—500-*mile skip*. The first zone of reception, if we consider the transmitter capable of getting out all rays down to the horizontal, lies between 500 and 2,000 miles. The second zone of reception lies between 1,000 and 2,000 miles; the third between 1,500 and 2,500 miles, etc. It will be seen that there are no secondary skips or zones of non-reception after the first skip distance. The diagram for this ray is, therefore, not carried out beyond 2,500 miles. In the region between 1,000 and 1,500 miles, we have two kinds of rays, one family having suffered one reflection and the other family having suffered two reflections. In the region between 1,500 and 1,750 we have three kinds of rays, and again two kinds between 1,750 and 2,000. Beyond 2,000 there are always three or more kinds of rays, due to the overlapping of the zones. If we take into account a certain amount of absorption in the lower rays, which is usually inevitably the case, and cut off the 3° next to the horizontal, we find that the first zone of reception falls between 500 and 1,750 miles, but that the zones still show a good overlap, so that there is no danger of any missing region developing further out. Now consider a much shorter wavelength showing a 1,500-mile skip. We find that if we include rays at the horizontal, the first zone falls between 1,500 and 2,000 miles; the second between 3,000 and 4,000, leaving a wide gap between. The third zone falls between 4,500 and 6,000, with a somewhat narrower gap between zone 2 and 3, and that after 6,000 miles no further missing regions develop. For this condition the diagram stops at 8,000 miles, it being unnecessary to carry it any further. If, however, we again limit the lower side of the ray by a ground absorption or any other artificial means, sich as the use of a suitably arranged reflector or by special means of tuning the antenna system, we find that the first zone of reception is very narrow and lies between 1,500 and 1,750 miles. For the second zone it lies between 3,000 and 3,500; for the third, 4,500 and 5,250; for the fourth, 6,000 and 7,000; for the fifth, 7,500 and 8,750, and for the sixth between 9,000 and 10,500 miles. In other words, it would be necessary for a ray to travel almost to the antipodes before the condition of alternating regions of reception and non-reception is done away with. This, of course, does not represent an actual case, because the layer could not possibly be even approximately at a uniform height over so great a distance. The discussion shows, however,

the general trend of affairs as they exist, and by observing the primary and secondary skips produced by such short wave radiations it has been possible to get certain checks on the general theory. It should also be pointed out that these missing regions will occur at somewhat longer waves if the layer becomes of sufficient height. Experimental data have been collected along these lines, and there is sufficient evidence to indicate that this general conclusion agrees with the facts.

It is possible to analyze the situation graphically in another way which presents, in a clearer way, the varying conditions as the height of the layer is changed. Figure 3 shows the values

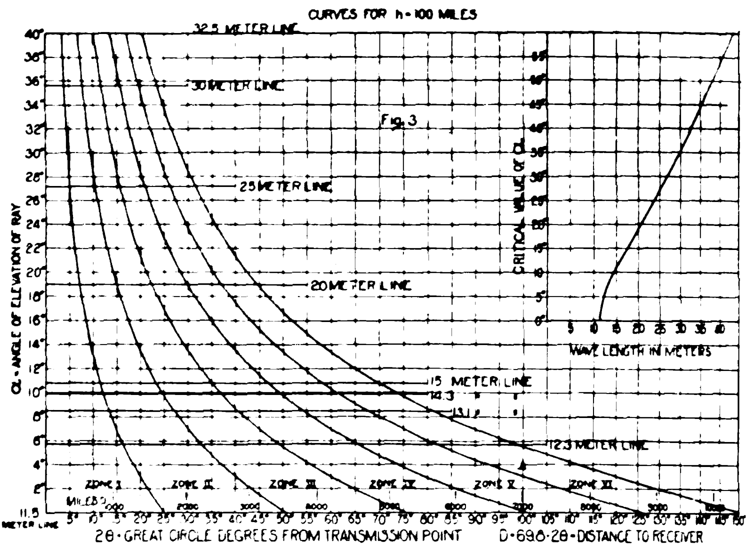

FIGURE 3

of θ corresponding to different values of α for the different zones of reflection, and for rays varying from horizontal to 40° with the horizontal. To find the position on the surface of the earth where any one of these rays come down, it will be necessary to find the value of θ, which corresponds to any given value of α. Assuming that the rays coming down from the sky will be reflected up again at the same angle, which some of them at least will do, if they will strike a sufficiently large piece of horizontal flat ground or water, the zone where the ray comes down after two reflections from the layer is shown by the next curve zone, No. 2, and so on for succeeding zones. Figure 3 is drawn for a Heaviside layer of 100 miles, which corresponds very accurately

to the mid-day height over the American continent for the Spring of this year. In order to determine what angles are actually available for useful transmission, it is necessary to take account of the critical values of α, and therefore of the variations of the same with wavelength. The curve in the upper right-hand corner of Figure 3 gives these data and from values taken from this latter curve, we can draw straight horizontal lines corresponding to different wavelengths on the main diagram. All portions above these lines indicate, for that particular wavelength, those higher angles of radiation which are wasted as far as long-distance transmission is concerned. For instance, using a wavelength of 32.1 meters, it is possible to utilize rays of as high an angle as 40°, but when using the 15 meter wavelength, all rays higher than 10.8° are useless. They may be all right for communication with other planets, but they never return to the earth. The limiting angle on the lower side is more difficult to specify as it differs greatly with different antenna installations and the method of exciting antennas. An antenna may be so excited as to exclude rays of a certain angle which will certainly be very disadvantageous on certain wavelengths for reaching certain portions of the earth's surface. On the other hand, an antenna close to the earth is liable to have a few degrees near the horizontal taken out by the earth's absorption. It is, however, certain that the shorter the wave, the nearer we can come to using rays near the horizontal, the amount of absorption depending on the ratio between the height of the base of the antenna above the earth and the wavelength in such a way as to greatly favor the low angle rays for very short waves. Another interesting thing comes out of the diagram, and that is, that it indicates a distinct limit as to the shortest wave possible for any long distance work whatever. That wave for this particular diagram, with a layer 100 miles high, is 11½ meters. In this connection it is interesting to note that while this laboratory has repeatedly communicated with the Radio Corporation station 6XG at Oakland, California, and with the Radio Corporation station 9XA at Denver, Colorado, on 11.8 meters, it has never been possible so far during the month of March to communicate on 11 meters. It is expected, however, that this will be accomplished during May or June—or possibly even during the latter part of April; because the Heaviside layer will be somewhat lower at that time, which will so modify conditions as to make a shorter wave possible. The use of the diagram can best be understood by an actual case. For instance, for 20 meters, we see from the insert

curve on the right of Figure 3, that the 20 meter line falls at about 19°. This gives the skip distance of 7.2 great circle degrees and the farthest zone of reception in the first zone extends to 25 great circle degrees. If now we drop the perpendicular from the intersection of zone 2 curve with the 20-meter line to the intersection of that perpendicular with the zone 1 curve, we see that it cuts that curve at 7°. If we are able to utilize radiation between the angle of 7° and 19° with the horizontal, we will never have any other skip regions opening up beyond the first. In other words, there will be no region of non-reception after the first skip. If, however, we drop to 12.3 meters we find that the critical value of α for this wavelength is 5.7°. The initial skip distance is 16.5 great circle degrees, and the limit of reception even for a horizontal ray is 25°. This shorter wave gives a longer skip and a much narrower zone reception. If we take the intersection of the 12.3-meter line with zone 2 curve and drop the perpendicular from there, we see that it does not intersect the zone 1 curve; there is a large gap from 25° to 32.5°, where there is certain to be no reception. This gap has been actually experimentally discovered a number of times. If we take the intersection of the zone 3 curve with the 12.3-meter line and drop the perpendicular we find that it just barely hits the zone 2 curve. Since the rays probably do not actually come quite down to horizontal, it would seem reasonable to expect a gap at 50° (great circle) from the transmitter. Beyond this, however, we would not expect gaps to occur, unless we are working into a region towards darkness where the layer is getting higher. This will be considered as a special case later.

The general nature of the influence of the height of the layer on the lower wavelength limit and the distribution of the zones of reception may be seen in the succeeding Figures 4, 5, 6, and 7, which are plotted for layer heights of 150, 225, 300, and 500 miles, respectively. One hundred and fifty miles represents mid-winter, mid-day conditions or late afternoon conditions in the Spring and Fall. It may also be considered to represent morning conditions at similar seasons of the year. Two hundred and twenty-five miles represents conditions approximately as they exist at midnight: summer nights and 300 miles conditions for the middle of the night in Spring and Fall. Figure 7 for 500 miles represents conditions approximately as they often exist during the middle of the night in mid-winter. The following points are of particular interest in connection with curves shown in Figures 3 to 7, inclusive. A critical wave-

length, below which no long-distance communication is possible, is shown to be:

11.5 meters for a 100-mile layer
14 meters for a 150-mile layer
16.5 meters for a 225-mile layer
19 meters for a 300-mile layer
25 meters for a 500-mile layer

If we take curve 6 as fairly representative of average night time conditions and compare it with curve 3, which actually represents conditions for mid-day in the month of March, this year, some interesting differences in the pattern on the surface of the earth

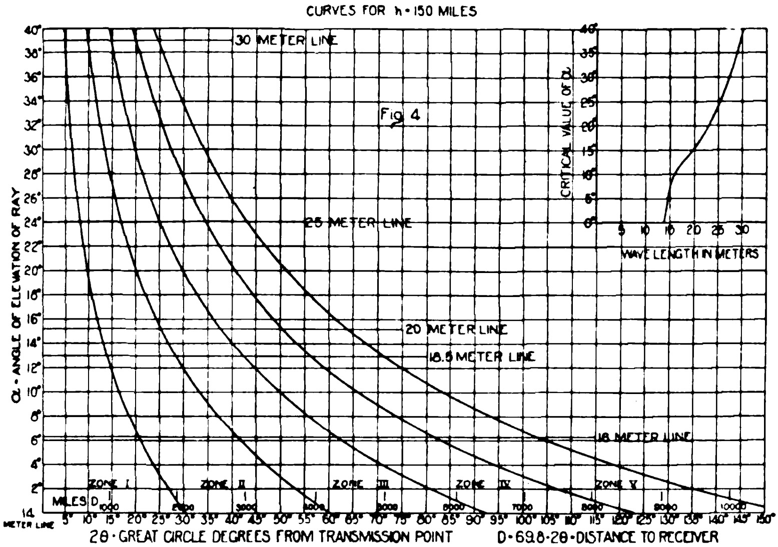

FIGURE 4

produced by the alternating zones of reception and non-reception are to be brought out.

Consider 20-meter transmission. When the layer is at 100 miles, the skip distance is 7° and there are no skip regions beyond the first. Rays of higher angle than 19° are useless, but when the layer is at 300 miles, rays higher than 7½° are useless and the initial skip distance is 30½°, which is somewhat over 2,000 miles. There is a very wide gap from 43° to 61°, that is, between 3,000 miles and 4,250. Following this gap there is a zone of reception up to 6,000 miles and then there is another gap beyond which reception is continuous. A glance at the diagram suffices to show why long distance work in the 20-meter band at night shows marked peculiarities and why communication on still

shorter waves is impossible. These remarks must not be interpreted to apply to transient or freak conditions. Some interesting conclusions can also be drawn as to relative strength of signals, if they are received at all, under these two conditions. For a point 5,500 miles away, under conditions shown in Figure 3, reception is only possible after four reflections, whereas under conditions shown in Figure 5, only two reflections are necessary. There is no theoretical reason so far for leading us to believe that there is any mechanism of absorption whatever in the upper layers of the earth's atmosphere for these frequencies, or at any

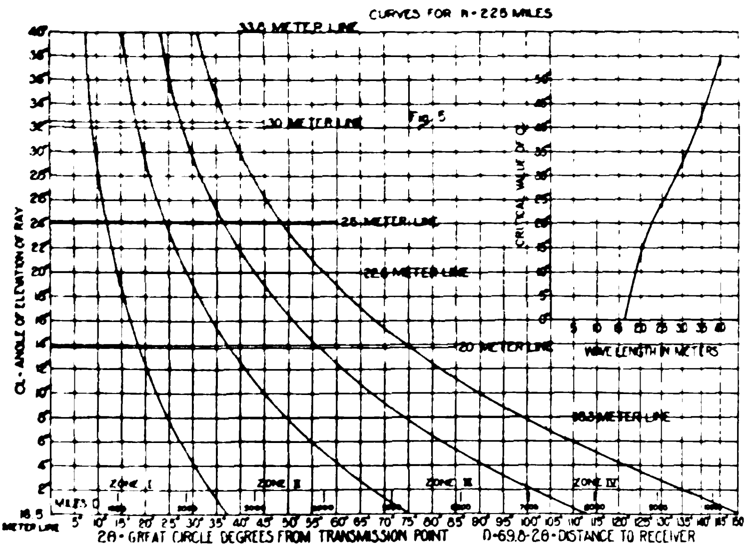

FIGURE 5

rate if such absorption exists, it is exceedingly small. It is true, however, that a great deal of energy is lost after a reflection from the earth's surface. We would expect, therefore, that signals under conditions shown in Figure 6 would be much stronger, and this, as far as information goes, is actually the case. It is also true that many of the nocturnal transmissions on 20 meters have not been observed at points sufficiently remote from the transmitter to get positive results. It follows in general, no matter what the height of the layer, that at points sufficiently remote, a good many different zones take part in the process of reception and many different rays of different life history have been brought down to the same receiver. This, of course, means an averaging out or a reduction in fading effects. This also is strictly in

accordance with facts. The main advantage of the short wave is that it is able to reach the desired point with a small number of reflections. It may be argued that the longer wave has the same opportunity, since low angle rays are present, but this is not strictly true since at the lower angle the longer wave rays are taken out by ground absorption much more readily than the shorter rays. The greater height of the layer in winter nights, however, favors all wavelengths above 25 meters, which is the limiting wavelength for that layer height, because it is possible for all waves to take longer jumps under these conditions. At

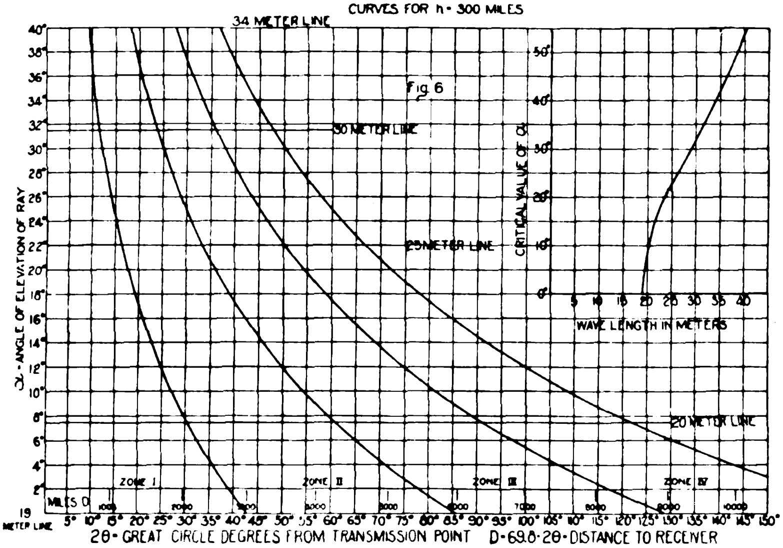

FIGURE 6

the same time a distant point receives energy from a smaller number of zones, as can be seen from an inspection of Figure 7. Therefore, the fading is liable to be somewhat more violent. These conclusions are borne out by practice. Some interesting conclusions can be drawn as to the probable maximum and minimum heights of the layer in this portion of the world. Knowledge of skip distances and their variations with the time of the day and year permit these calculations to be made. Based on the longest observed skips in the 40-meter band, the maximum height of the layer last winter appeared to be 550 miles. In connection with this figure it may also be of interest to note that since signals on 27 meters have not been observed to completely disappear during the winter midnight hours, the layers cannot

have been last winter over 706 miles high. On the other hand, 21 meters would repeatedly apparently disappear completely, which would lead to a calculated height of 405 miles. The average between these two extremes is 555 miles, which agrees very well with the height computed from observations in the 40-meter band. This perhaps explains why the height of 500 miles has been chosen to represent mid-winter, midnight conditions. Another interesting point is that the layer would have to rise to 3,300 miles to make a 40-meter wave completely vanish and never be received on the surface of the earth. This seems

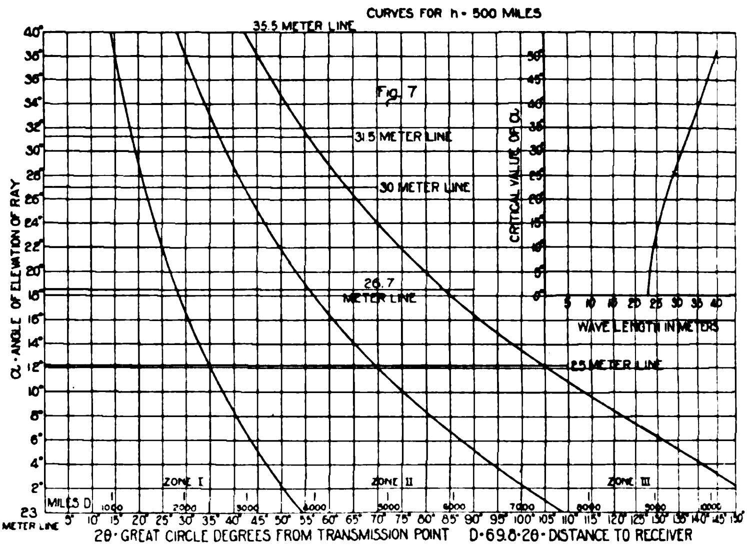

FIGURE 7

extremely unlikely unless perhaps over the polar regions in mid-winter. The evidence from the Polar regions does not indicate complete disappearance, but does indicate a very high layer during the winter and a very low layer in summer. The data are too scanty to warrant calculating the height there. Some observations are also at hand taken during the months of July and August of 1925, at which time, over a period of nearly a week, signals in the 20-meter band showed an abnormally short skip distance and indicated a layer height over this brief period as low as 51 miles. The limiting wavelength for a 51-mile layer would be 7 meters, but the skip distance would have been several hundred miles and the pattern on the surface of the earth would have shown very narrow zones of reception and very wide zones

of non-reception. In other words, it would have been quite accidental if communication had been established under such conditions and it would be persistent only for a short time. Even a small variation in layer height would have flickered these zones back and forth so as to give extremely unstable conditions. To communicate on 8 meters would require the layer to come down to an equivalent height of 61 miles and the conditions would be the same to those just described. For 5 meters the height would have to be 41 miles, and it seems extremely unlikely that this will occur for sufficiently long periods to make experimental work worth while. If such work is attempted, it should be done in the middle of the summer and the observers should be scattered out between 300 and 1,500 miles from the transmitting station.

The experimental data obtained during the daily tests in the month of March this year, using waves between 11 and 26 meters, have been made possible by the cooperation of the operators at the Radio Corporation stations 9XA and 6XG, Denver and Oakland. It has been possible to observe the primary skips at Denver and the secondary skips, on different wavelengths of course, at Oakland, and to correlate this information. Since it has been impossible to get successful communication at 11 meters, but has repeatedly been possible on 11.8 meters, we can calculate the upper limit of the layer height to permit communication on 11.8 meters and this comes out to be 116 miles. The information based on primary skips shows the layer height to have been close to 113 miles. The information from Oakland, based on secondary skips, shows the layer height to have been 102 miles, and other information, based on observations at lesser distances by other stations, and on other wavelengths, particularly the twenty-meter band, give a calculated height of 110 miles. This is considered to be a very remarkable agreement. The skip distances observed by Denver were, for some of the waves, also secondary skips and these also calculated to practically the same height. Furthermore, the secondary skips observed by Denver have been checked as primary skips by other observers at half the distance in entirely different directions, notably by 9CXX at Cedar Rapids, Iowa, and 4XE at Winter Park, Florida. It does not appear, then, that the agreement in results is a matter of coincidence. These transmissions will be continued with the expectation that the layer will lower to average mid-day height somewhere in the neighborhood of 75 miles in the approaching summer, which will permit the use of waves down to 9 or 10 meters.

The curves herein presented refer, of course, to an ideal condition, namely, for a layer of unvarying height. It is somewhat difficult to get a graphic solution of the problem for layers of varying height, but as information comes in and more data become available, considerable progress can be made in this direction. The variation in the height of the layer is, of course, particularly interesting for East and West transmission. Figures 8, 9, 10, and 11 constitute an attempt to show the general nature of the peculiarities in East and West transmission which may be expected. The figures are obviously very far from correct

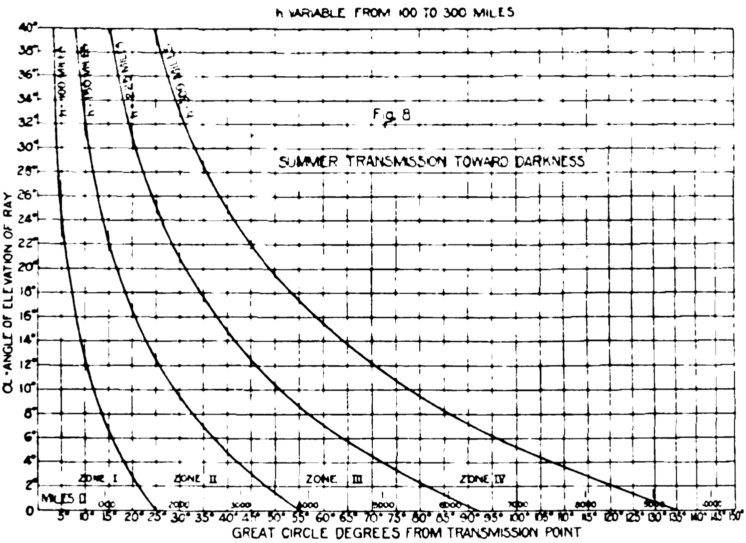

FIGURE 8

and more accurate figures could be constructed if it were deemed worth while in the light of the present information—nevertheless, they do throw much light on the situation. These curves in Figures 8 to 11 are drawn with differing layer height for each zone of reflection, which is, of course an exceedingly poor approximation, since the energy received in any zone may be reflected from heights not corresponding to that zone, nevertheless, the curve shows a marked peculiarity which should perhaps be called, in a certain sense, a non-reciprocity in transmission and reception. For instance, looking at Figure 8 for summer transmission towards darkness, starting from high noon at the location of the transmitter, we may pick a given wave such as 20 meters and by inspection of Figure 3 we see that rays of as high an angle as 19°

are available. The first region of reception is a broad region extending from 7 to 25°. For zone 2, however, by inspection of Figure 5 we see that rays up to 15.2° may be used so that the second region of reception overlaps the first. However, when we get out to zone 4, inspection of Figure 6 shows that rays up to only 7½° may be used, which do not quite overlap zone 3. However, the pattern is one of nearly continuous reception from 7° outward. There is merely a small gap in the neighborhood of 95°, but if we look at Figure 9, where the transmitter is at midnight, we are obliged to start with rays no higher than 7½° and no

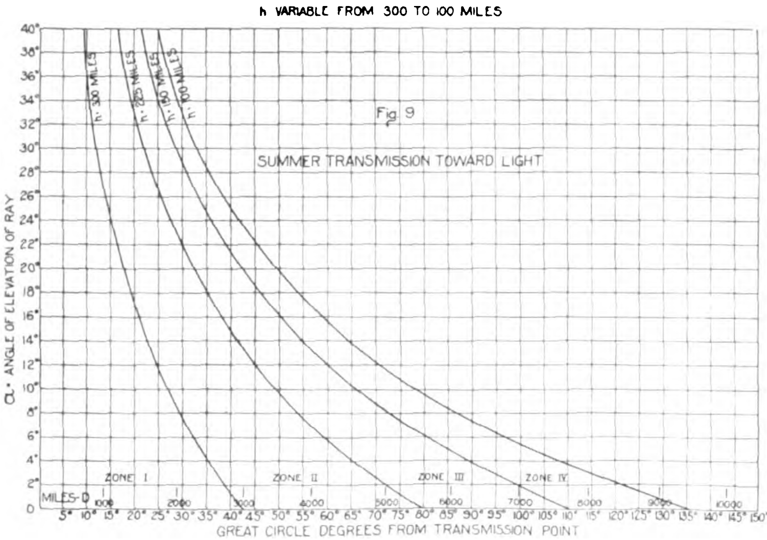

FIGURE 9

reception begins until 31°, which is beyond 2,000 miles. Moreover, rays of higher angle having been cut off at the beginning will not exist thereafter; the result of this is that there occurs a very wide gap between zone 1 and zone 2 of reception, namely: between 33 and 55°. After that there are no gaps. Obviously the zone patterns on the earth are very different for the two cases. It would seem, however, that after a ray actually reaches a given point, it should be possible to put a transmitter at this point and send that same wavelength back in the opposite direction and have it received at the original transmitter. However, we are really dealing with a complex band which is being refracted through an electron atmosphere in the presence of a magnetic field and it seems reasonably certain that the return

ray or rays would at any rate, have entirely different states of polarization from the ray which started out. The irreversibility then consists in the different state of polarization and in the different character of the patterns on the surface of the earth made by the zones of reception and non-reception. This sort of thing is, of course, clearly emphasized in winter time as shown in Figures 10 and 11. Obviously, however, for extremely long East and West transmission, one must not use wavelengths which, when they encounter darkness in a high layer, will become lost because they exceed the critical wavelength for that particular

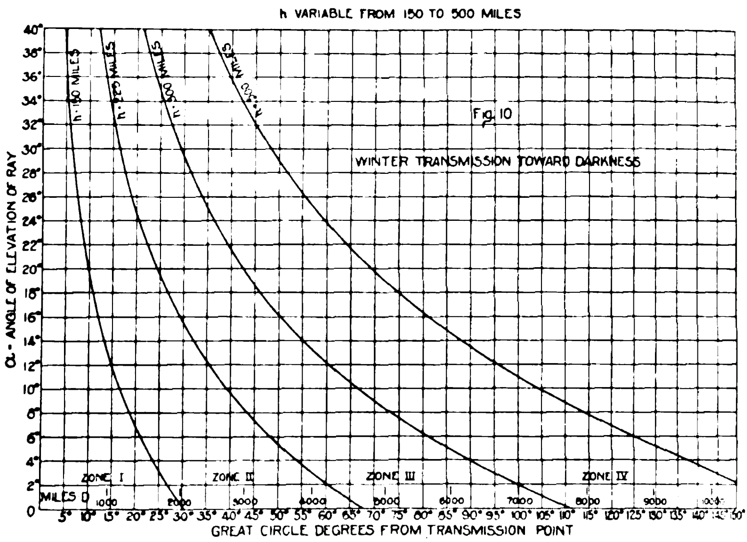

FIGURE 10

layer. If this be true, very long distance work East and West in the winter time should be limited to wavelengths in excess of 23 meters and in summer time to wavelengths in excess of 9.0 meters. At the same time, the waves should be, for strongest signals, fairly close to the limiting ray in order to have the smallest number of reflections and therefore, the least absorption.

As far as North and South transmission is concerned, the limiting cases would probably occur when winter occurs south of the equator, and again when winter occurs north of the equator. At these periods, transmission may not be wholly reciprocal. In the Spring and in the Fall, however, fairly uniform conditions should prevail over the entire distance.

In conclusion it may be stated that there is one station in

this country which does not appear to show a skip at all, or at least not at all in line with that shown by Naval transmitters and by other transmitters observed at this Laboratory. That station is 2XS of the Radio Corporation, whose signals are received at points from 200 and 600 miles distant, which, theoretically, they should not reach at all. A number of observations have been accumulated upon this station by this Laboratory, and practically without exception they show this anomaly. Several possible explanations have been advanced and they are given here for what they are worth, none of them, however, must be

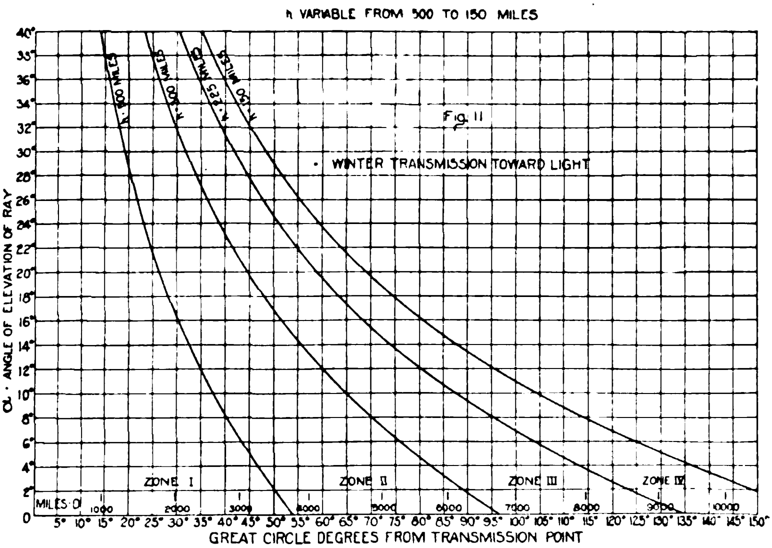

FIGURE 11

taken too seriously. First, that the signals travel entirely around the globe. This seems unlikely, because the signals are too strong. Second, that there may be an effect near 2XS, due to ionization from various sources, which are known to exist in the neighborhood of large manufacturing cities. There is little doubt that such ionization effects do exist, but that the electron density is sufficiently great to account for the refraction and production of a sky wave other than the one from the Kennelly-Heaviside layer, seems difficult to believe. It is understood that the radiator of 2XS is a horizontal polarized doublet, but this does not explain in any way the anomaly. Such doublets have been commonly in use at this Laboratory for a long time and without exception they show normal skip distance effects. The use of the

reflector at 2XS does not seem, theoretically, to account in any way for the anomaly. If the station were on a sufficiently high ground elevation, the ground wave could, of course, account for a very long distance before being absorbed. In this connection it should be pointed out that, with sufficiently elevated antenna, communication by the direct ray is always possible in such a way as to cut out the initial skip distance. This has been frequently demonstrated in aircraft tests by this laboratory.

SERVICING OF BROADCAST RECEIVERS*

By

LEE MANLEY AND W. E. GARITY

(RADIO CORPORATION OF AMERICA)

Much has been said and much has been written on the many troubles that arise in radio broadcast receivers as to what causes their failure and how to correct troubles when they occur. The radio sections of our daily papers and radio publications have devoted columns and pages in answering individual problems. These have been of invaluable assistance to the individual, but in nearly all cases have referred to specific conditions.

In this paper we will endeavor to group service problems under general classifications, prescribe methods of diagnosing them followed by a prescription for correcting them.

We believe that general methods may be applied in spite of the fact that there are so many different types of sets on the market, each one claiming individual distinction all its own. All radio sets, no matter what type, which fail to give satisfaction do so for a number of reasons that are fundamental.

In general, there are four basic pick-up circuits in use today: the so-called regenerative detector, the untuned radio frequency, the tuned radio frequency and the super-heterodyne. Any set on the market may be classified as using one of the foregoing types or possibly a combination of one or more. There are two additional types of pick-up circuits which have fallen more or less into oblivion and will not be found in general use in the broadcast receivers of today. They are the crystal detector and the straight audion detector which employs no form of regeneration whatsoever.

Receiving sets consist of a pick-up circuit, a detector circuit and an audio frequency amplifying circuit. In the pick-up circuit radio frequency amplification may be incorporated. The detector may be either a tube or a crystal. In the audio frequency circuit from one to three tubes are generally used. In multi-tube sets employing radio frequency amplifiers, some arrangement of circuit is made to suppress or control the tendency

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of the tubes to oscillate, when the circuits are tuned to resonance.

Any set on the market today may be grouped under one of the foregoing classes as to the circuit employed.

In much the same way that receivers may be grouped under circuit classifications, their failure to operate may be grouped under certain general classes, namely:

Lack of operating experience on the part of the user.
Location.
Defective accessories.
Open circuit.
Short circuit.
High resistance connection.

Lack of operating experience may be the result of not following out instructions carefully enough, or, as is sometimes the case, the instructions are not complete enough and are not entirely clear to the novice. It may be the result of insufficient instruction on the part of the service man who made the installation. Then, too, it may be the result of impatience on the part of the customer. It is a peculiar condition, but a fact nevertheless, that the first night a customer has a set, he feels that he should be able to get Chicago and points west from New York City. The responsibility for this condition rests with either the salesman who sold the set or the service man who failed to correct this fallacy in the customer's mind, or with the manufacturer of the set for over-advertising his product, and being a little too optimistic as to the possibilities of reception. A manufacturer who in New York City receives the Pacific Coast stations on his product is not justified in making a general statement that this can be repeated at will, giving the impression to the reader of the advertisement that that particular receiver will perform likewise in every other locality. That is incomplete advertising and should be discouraged as it has a detrimental effect on the industry as a whole, and results in unnecessary service costs.

Under the caption of location many factors must be considered. The type of building in which the installation is made, the proximity to steel buildings, power lines, trolley and railway lines, and the geological and topographical conditions surrounding the installation are all important factors. Certain areas appear to be "dead" to certain stations, while at the same time particularly good for others. We believe that this is due not to the area being "dead," but to a distortion of the wave front from the transmitting station, causing it to be deflected in such a manner

as to render reception of signals from that station very difficult or impossible in that particular location.

Under defective accessories we may include defective tubes, batteries, loud speakers, antenna and ground installations, also improper battery connections. Many sets fail or are returned to the dealer as unsatisfactory because of poor antenna and ground installations. Many a set of good quality and capable of delivering satisfactory results fails because the loud speaker that is used with it does not have the proper electrical characteristics to operate satisfactorily in conjunction with the receiver. Tubes will also cause trouble as they are subject to certain defects incidental to fragility.

Open circuits are generally found in the movable connections of the set such as a condenser pigtail, loop leads, loud speaker leads, and any other connection that is subject to movement or vibration in the normal operation of the set. Open circuits may also result from burned-out transformers or from mechanical failures in telephone jacks, rheostats, and switches.

If a set has been once tested and found to be O. K., short circuits rarely occur. When they do it is the result of a mechanical failure of the moving parts or of tinkering with the mechanism of the set. It will sometimes happen that the pigtail of a moving element of the receiver will break and fall in such a way as to cause a short circuit of that element. This is particularly true of the pigtails of variable condensers. The principal cause of short circuits that occur in the normal operation of a set is in the tubes. If the filament of the tube should break there is a possibility of its falling in such a way as to cause a short circuit between itself and the plate and grid elements of the tube. When such a fracture of the filament occurs the voltage of the "B" or "C" battery, as the case may be, is short circuited through the conductors involved. This type of short circuit is generally of very brief duration as the filament will generally burn out as soon as the short circuit occurs. A contact between the grid and plate element of a tube is a more serious type of short circuit, resulting in the rapid deterioration of the "B" and "C" batteries, and may possibly cause a burn-out of the transformer windings in the circuits involved.

The foregoing troubles are relatively easy to check up as they are immediately apparent or can easily be located by a continuity of circuit test.

The most difficult type of failure to locate is that caused by a high-resistance connection. It is not only difficult to locate, but

it is difficult to determine. This condition will cause the set to operate indifferently with rather unsatisfactory results. This condition is sometimes mistaken as location trouble. A high resistance is possible at any connection in the receiver. Soldered connections that are soldered with a corrosive flux that has not been properly treated after the soldering operation are probably the worst offenders. Weak mechanical springs in telephone jacks and switches may also introduce high resistance connections.

Radio sets, like individuals, are very much the same the world over. They fail or succeed according to a few fundamental laws. They are subject, as it were, to the same ills. The doctor can diagnose the trouble in a man's system whether he be well dressed or poorly dressed, whether his name be Smith or Jones, because he knows the fundamental laws governing the human system and is not confused by size or shape or a difference in physical dimensions.

One doesn't have to be a radio engineer or a radio expert to be able to service a radio set, but one does need experience to become adept, and some knowledge of the fundamentals is valuable. One must be, of course, familiar with the various parts that are commonly used in radio receivers such as rheostats, jacks, etc., and must know, in a general way, the function of each.

Given a first-aid manual, the man in the street with an ordinary amount of common sense and an ability to read, might go out and administer first-aid treatment and, if he followed the directions properly, might effect a recovery. A doctor could do no differently. His experience would permit him to handle the case more skilfully and his intimate knowledge of the workings of the human system would permit him to diagnose the case more quickly from the apparent symptoms, but the man with the first-aid manual would produce the same results in a little longer time and yet he knows nothing of medical science.

For instance, what does a doctor do when he is called in to treat a sick person? The first thing he generally does is to feel the pulse and while doing that he starts a series of questions as to the length of time the person has been ill, where the pains are, etc., and he may even go as far as to inquire into the family history. Let that be the practice of the radio service man. Do not immediately get out the tool bag and start pulling the set apart, but try to find out what the difficulty is by questioning the customer. What would one think of a doctor if at the first sight of every patient, he started to operate, and yet you will see a service

man start in immediately to pull the set out of the cabinet and look for trouble, and the trouble may be in a battery connection.

What we will attempt in this paper is to outline a first-aid manual for the treatment of "sick" radio sets; that will enable the man who is not a radio engineer and who has only a slight knowledge of the art, to recognize trouble and make the necessary repairs. We have avoided, therefore, all theoretical considerations so far as possible and will treat the subject from a practical viewpoint and refer only to theoretical discussions when absolutely necessary. We have prepared a list of complaints that are most frequently heard, and we will analyze each complaint as to the possible reason for it.

Let us start with a suggestion to the dealer or, for that matter, to anyone who sells a radio receiver. Test all sets before sale. This takes but a very few minutes and will surely pay well in avoiding dissatisfaction as well as time that is sometimes necessary to service a defective set that has been shipped to a customer. A radio receiver that is working properly today does not as a rule go bad tomorrow, and if such an installation does fail, the dealer may feel that the trouble is due to a defective accessory rather than the set itself. When the service man is called on to service such a set he has the confidence that the set is O. K. and he will immediately be able to concentrate on the real probability of failure rather than imaginary ones.

Then, too, if the dealer would acquaint the customer with the limitations of radio reception, what to expect and what not to expect, service problems would be minimized. Acquaint the customer as to the probable length of time his batteries will last. This is quite important, and if followed out, will avoid some very disagreeable service jobs. For example, when a man purchases a radio set he becomes quite enthusiastic and will read all available literature on the subject, and at the end of a month he has absorbed just enough information that may prove dangerous. About this time the signals on his set will start to decrease and he will remember having read somewhere that this might be caused by a defective transformer, and he immediately gets out the tools to make the repair, and then the dealer has a regular service job on his hands. Had the dealer in the first place acquainted the customer with the facts concerning the life of the batteries, the customer would be more than likely to recall such information and take the proper steps to renew them.

The question has been asked at times, "What should the service man's equipment consist of?"

He should carry the necessary tools and apparatus to be able to run a complete test on the set to be serviced and be able to make any minor repair necessary. We would suggest the following items:

Set of tested tubes.
Multi-scale voltmeter of good quality.
Pair of head phones.
Large and small screwdrivers.
Small soldering iron.
Solder and non-corrosive flux.
Spare wire and tape.
Test-leads with clips.
Pipe cleaners.
Large piece of cloth.
Set of B and C batteries (small).

When a service man goes into a customer's home he is usually going there as a representative of a commercial establishment. He should be instructed to be courteous and considerate. If he must take a set out of the cabinet for adjustment he should use the piece of cloth provided in his kit to protect the surface of the table he works on. He should answer all questions asked him no matter how absurd they may appear to him. The customer generally has one question that he would like to have answered, and in his mind the service man must be an expert, in order to be able to do such work, and so he unburdens his mind. The service man should respect this attitude on the part of the customer and should do his best to point out the fallacies tactfully and set the customer right in his ideas about radio. The service man should make the customer enjoy his visit and if this is done the service man becomes a valuable asset to a business and is a potential salesman.

The service man, before he starts to make any adjustments other than turning on the set and trying the various controls, should question the customer as to how it happened, the time, place, and conditions surrounding the failure. Such questions as the following:

How long has the set been in operation?

Was the set operating satisfactorily up to the time of failure?

Were you tuning the set when the failure occurred?

If so, what control were you moving?

Did you make any change in the connection of the batteries, if so, what were they?

Did it suddenly stop operating?

Was there any squeal or howling sound just prior to failure?

Were you moving the loop?

Did the loud speaker fall?

Is the antenna OK?

In short, have the customer re-enact the conditions at the time of failure. Get all the symptons and an astonishing amount of time may be saved in running down the difficulty. If sufficient questions are asked, the customer will generally give you the real cause of trouble or he will suggest something to you in the course of inquiry that will point out just what the cause of failure was. Sets as a rule do not go bad of themselves. The failure usually occurs while some operation is taking place, such as plugging in the loud speaker, turning the condensers or making a change in the battery connections.

The length of time that a set has been in operation will be an indication of various types of trouble. A set that has recently been installed is subject to a certain type of failure, while a set that has been in operation for a year or more, is subject to other types of failure.

If a set has been installed for a period of two weeks or less, outside of the inability of the customer to procure the desired results, there are only a few reasons why the set should fail. They are:

A defective tube.

Defective battery or battery connection.

Loud speaker connection loose in telephone plug.

Burn-out of transformer.

Of course, there may be other reasons, but these are the most common and are given in the order of their probability of occurrence.

If the set has been in operation for a month or six weeks and has been giving satisfactory service for that period, the cause of failure is generally due to the weakening of the batteries.

If the set has been in operation for a period of six months or a year, the possibilities of trouble will increase. If the failure in this type of installation has been gradual, the first thought would be that the tubes were becoming deactivated through continual use.

If the breakdown was sudden, a mechanical failure might be expected in one of the movable connections or pigtails. A burned-out transformer could be expected in difficulties of this sort. If the trouble is due to a noise condition, the failure might be ascribed to dust or dirt accumulations on the condenser plates

or other important parts of the receiver. The defect might also be due to a soldered connection. It will require, as a rule, a rather long period of time for a soldered connection to corrode to such a degree as to cause this condition. The local atmospheric conditions under which the set has been operating may have some bearing on the cause of failure. If the set has been operating near the seashore and has been subjected to the action of salt atmosphere it may have caused sufficient corrosion of the connections or other metallic parts to introduce high resistance or leakage path. Moisture may saturate the cheaper grades of insulating material to such an extent as to cause high-frequency short circuits.

If a set has been operating for a long period of time and has given satisfactory results and then develops noises and scratching sounds, one should not look for a loose connection in the wiring of the set, but rather look for an open circuit in the moving parts. Worn mechanical parts are often mistaken for loose connections in the wiring. The wiring is absolutely stationary and it is not at all likely that it will be disturbed in the ordinary use of the set so as to cause a failure due to a loose connection. Vernier drive shafts and vernier plates will wear loose and while apparently they are making perfect contact to the metal surfaces of the condenser when the set is brought into a critical condition, as is the case when receiving distant stations, will cause noises that might be thought due to a loose connection in the wiring.

Another item to be considered in the servicing of radio sets is the cost of the original apparatus. Radio, like any other merchandise, is a matter of price. As a rule, the more you pay for a set, the better should be the quality of the equipment you get and you may reasonably expect longer and more satisfactory service from it. In a high-grade receiver the mechanical failures are less frequent than in the cheaper grades of sets. The same is true of electrical failures. The cheaper grades of sets are much more subject to climatic conditions then are the better grades.

We have compiled a series of complaints in such terms as they are received by the dealer, and we will take each up in turn as to what it suggests as the possible cause of failure.

"The set just stopped operating. It was giving excellent results, but it suddenly stopped." This complaint is quite unsatisfactory from a service man's point of view. It does not suggest anything definite and it may be the result of many factors. Trouble generally occurs when some operation is taking place, whether it be tuning or making adjustments or plugging in the loud

speaker, or revolving the loop. The service man should inquire just how the failure took place, just what the customer was doing when the set failed. If the failure occurred when some adjustment was being made, he should look for a broken connection or a mechanical breakdown in the control being used at the time. There are several causes of a set failing completely and suddenly, namely, a burned-out tube, a burned-out transformer, a broken connection, or a short circuit. A broken loop connection will also cause complete failure as well as a burned-out loud speaker. Of course, there are many reasons why a set may fail to function, but the list just given represents the principal causes for a complete and sudden failure.

A burned-out tube will be immediately obvious and should be replaced. A broken battery connection or pigtail may be located by inspection and necessary repairs made. A defective loud speaker may be determined by replacing the loud speaker with a pair of head phones and noting whether the head phones operate satisfactorily.

In making all checks on defective sets, the first thing that the service man should do is to light the tubes to their proper brilliancy and then plug the loud speaker in and out of the jack. If the B battery is properly supplying the tubes in the amplifying circuit, a loud click will be heard in the loud speaker. If there is a jack provided on the detector tube, repeat this, using the head phones. In other words, see that there is a B battery voltage at the plate contact of each tube. In the radio-frequency tubes, if used, measure the voltage across the tube contact springs in the socket. This may be accomplished by removing the tubes from the sockets and making direct contact with the springs. There is another possibility of failure in sets that employ a large by-pass condenser which is connected across the B battery supply. In event of this condenser becoming short-circuited, it will cause the B batteries to drop in voltage very rapidly and if the short-circuit is complete enough, the batteries will heat up. This can be very quickly determined by breaking the connection through the negative B battery. If a heavy spark occurs, it is an indication that there is a short circuit in the B battery supply which may be due to this condenser. In testing this condenser should, by chance, the tubes be lit when the B battery connection is broken, a small spark will be present. The small spark is due to the normal drain on the B batteries and represents the total plate current of the tubes in the set. If the tubes are not lit, no sparking should occur when the battery connection is broken,

but if there should be, this is an indication of a short circuit within the set. Of course there is the possibility of a wire breaking free in the set itself and falling in such a way as to cause a short circuit, but this is immediately apparent on inspection. There is also a possibility of a short circuit of the elements in the tubes.

"I cannot get distance," is a general criticism that is met with radio receivers of all types.

The most general cause for this complaint is the inability of the customer to tune the set properly so as to get the most out of it. The obvious remedy for this is to instruct him further in the operation of the set. The service man should spend an evening with him and show him just how to do it, and once the customer knows that the set is capable of receiving distance, he will never admit that he cannot get it.

A defective tube will sometimes prevent distant reception. Perhaps one of the tubes used in the radio frequency circuit is not particularly adapted for that purpose, but will make an ideal detector or audio frequency amplifier. Try interchanging tubes so as to get the best possible combination. Do not make a practice of interchanging tubes after the most satisfactory combination has once been determined. This is particularly applicable to dry-cell tubes. Because of their delicate structure, it is not well to subject them to excessive handling.

Location and local conditions materially affect the ability of a set to receive distant stations. Antenna construction and ground conditions are important factors. If a loop is used, the shielding of nearby metallic bodies will affect the results. In a case of loop sets it is advisable to install the set near a window. This is particularly true in the latest types of homes and apartment houses which employ in their construction metal lathing which acts as an electro-static shield to the incoming signals. In the case of sets employing antennas, it will be necessary to experiment with antennas of different length and in different directions. However, before the service man blames the location for the failure, he should take a set of similar make which he knows operates satisfactorily in another location, and check the results in the doubtful location, comparing results received on the new set with those of the standard set. In some instances, the service man is prone to use location as the cause of failure to receive distant signals, whereas it may be due to a defective part in the radio set.

"The signal comes in loudly and then dies out." This is generally due to the phenomenon of fading.

However, should this condition exist on the local stations, as well as the distant stations we would be inclined to suspect either a defective A battery connection or a defective A battery. A soldered connection in the filament circuit that has become corroded or broken for some unknown reason while not completely open so as to cause the tube's failure to light, but just making contact, will cause this condition. This defective connection, at times, will become highly resistant; sufficiently so to cause a decrease in the filament brilliancy. This condition is generally obvious as the brilliancy decreases at the time of the fading. This condition is rarely met, but it is extremely difficult to locate the defective connection and requires careful inspection of every connection.

This condition may be brought about by a defective dry-cell type A battery. In this case, it is due to a local action within the dry-cell. The internal resistance of the cell will vary, due to this local action, and cause effects similar to that caused by the defective connection just described. In the case of dry cells, it is sometimes necessary to readjust the filament rheostats slightly in order to restore the set to its normal operating condition, and at times, the set will recover itself. In a storage type A battery this condition may be brought about by a so-called "treeing" effect. This condition is generally present only in old storage batteries and is the result of a lead tree building up on the plates in such a way as to penetrate the separator. This lead tree builds up until it touches the opposite plate and causes a momentary short circuit of the plates involved. The short circuit burns off the lead tree and immediately the building up process is started again. When the short circuit occurs there will be a slight decrease in the total voltage of the battery, which will cause a slight decrease in the filament brilliancy resulting in a fading effect. In cases of this type, the fading periods are only momentary and recur at fairly uniform time intervals and are present on all positions of the tuning scale.

A similar condition may be caused on sets employing an antenna, by swinging of the antenna or lead-in. This condition should not be confused with the fading phenomenon and may be identified by the fact that the volume of the signal will not change, but will swing in and out. The particular danger to be encountered is when the antenna is close to a metallic or other conducting body and in swinging, touches the same, causing a momentary short circuit. This is recognized by a click in the loud speaker when the ground occurs.

"I don't get any volume; the signals are weak." If this condition is persistent and investigation shows that good results were never had on the receiver, and the location has been carefully checked by a similar type set, the difficulty would seem to be due to one of the following causes:

Inferior grade of set, not capable of producing good results.
Inexperience, lack of knowledge of tuning.
Defective tubes.
Defective batteries.
Reversed A battery connection.
Poor antenna location or installation.
Defective ground connection.
Defective loud speaker.

These are listed in their order of importance and occurrence. If the receiver is of an inferior quality some advantage may be had by replacing the grid condensers and audio-frequency transformers with similar instruments of better quality. If it is due to lack of knowledge, it is the duty of the service man to instruct the customer more fully. Defective tubes should be replaced. This condition may be checked by replacing the entire set of tubes in the defective set with tubes that are known to be O.K. A defective battery may be located by checking the voltage. It is generally conceded that a B battery whose voltage has dropped 25 per cent. from the normal rating of the battery, should be discarded. If the A battery connections are reversed on receivers employing audio frequency amplification, little or no amplification will be had. This is easily checked by reversing the battery leads. Just when an antenna is defective is very difficult to say, as there are so many local conditions which play important parts in the success or failure of an antenna installation. In general, the antenna should be removed as far as possible from all objects, such as trees and buildings, and metal objects in particular. In general, the higher the antenna, the better will be the results obtained. If the antenna is erected in the vicinity of a high-tension transmission line, it should be erected so that the line of the antenna is at right angles to the transmission line. The antenna should be carefully insulated at all points throughout its length including the lead-in. It will sometimes happen that a set employing an antenna operates quite satisfactorily during periods of dry weather, but during, and after rain storms, the operation of the set becomes rather indifferent. This condition is generally due to a defective insulator which breaks down during periods of wet weather, causing high losses. An opposite

condition may be had where the set operated more successfully during periods of wet weather than it did in dry weather. This would indicate that the moisture in the ground enhanced the value of the ground connection by reducing the ground resistance of the circuit. Some care should be exercised in the selection of a ground and the service men should not necessarily use the first ground available. Several ground connections should be tried and an effort made to determine the one giving maximum results, and this one used. In the present day equipment it seems to be customary to use an aperiodic circuit in the antenna, and for that reason defective grounds do not manifest themselves quickly. In antenna sets employing a series antenna condenser, a defective ground will cause the antenna condenser to tune very broadly.

A loud speaker that has been connected into a receiver with the polarity reversed will, after a time, become demagnetized and result in very poor volume and quality.

"The volume was great for a short time, but suddenly started to weaken." This condition generally results from using an excess voltage on the tubes. It is particularly true in the case of sets employing dry cell tubes. The customer sometimes has a peculiar psychology and believes that by turning the rheostats of the tubes on full that he is getting better results. With the tubes used today, employing thoriated tungsten filaments, this is a fallacy. Operating tubes using this type of filament at a greater than normal voltage deactivates the filament very rapidly and decreases its useful life. Under no consideration should a thoriated tungsten tube be operated at a voltage higher than the rated voltage as indicated by the manufacturer. A defective battery that has deteriorated abnormally will also cause this condition.

"I get one station well, but another station is weak and they are both about the same distance away." It is the general belief that this condition is caused by metallic obstructions, such as steel buildings, high-tension systems, railroads, etc., or possibly mineral deposits near on the earth's surface. It is believed that these obstructions cause either an absorption or a deflection of the radio waves which renders certain areas incapable of receiving signals from certain stations. You have probably all heard of the recent investigation carried on by the American Telephone and Telegraph Company, in which it plotted the signal strength of its New York station in different sections of the metropolitan area, and of the peculiar results noted. Certain

areas in Central Park were practically dead to signals from this station. There is perhaps no remedy for this condition and it is not the fault of any particular set, as this condition would be true whether a crystal detector or a super-heterodyne be used in such a location. Of course, the super-heterodyne circuit, because of its sensitivity, would respond to an extremely weak signal that would be inaudible in a crystal detector set, but for practical considerations, reception in such an area would not be satisfactory, while at the same time, excellent results might be obtained from other nearby stations.

"The volume used to be O.K., but has been getting weaker and weaker." This condition is generally caused by the normal decrease in voltage of the batteries. It may also be caused by the use of a slight excess voltage on the tubes which will cause a slower deactivation of the filament than described previously.

In the case of a recent installation, defective batteries should be looked for. Should the installation have been made a year previously, the difficulty might be due to the normal depreciation of the useful life of the tube.

"It works O.K. for a while, but suddenly a howl starts which sounds like a siren or a fog horn which can only be stopped by shutting off the set or cutting down the volume." This effect is due to a vibrating air column which is set up between the loud speaker and, usually, the detector tube of the set. The action is similar to that which results when a receiver of a telephone instrument is placed in front of the mouthpiece of the transmitter. This condition is generally caused by a microphonic tube in the detector socket. It may be due also to a loose element in some part of the circuit. A loose transformer lamination or condenser plate might cause the same condition. A popular theory of this condition is that the vibrating air column from the loud speaker causes a vibration of the filament in the detector tube. The vibration of the filament causes a variation of the tube characteristics which causes in turn a variation of the plate current, and an acoustic feed-back results. In loud speakers of the adjustable type, adjustment of the air-gap will sometimes eliminate this howl. In the case of non-adjustable loud speaker units it will be necessary to try interchanging the tubes in the sets in order to eliminate this condition. If interchanging the tubes does not correct it, place the loud speaker so that the bell points away from the set and place either the loud speaker or the set or both on pads of soft felt or sponge rubber. It is because of this effect that it is not advisable to place the loud speaker on

the top of the cabinet, unless the tube sockets are sufficiently cushioned.

This condition, however, usually occurs only when the set is operating at maximum output and the radio-frequency amplifiers are set in an extremely sensitive condition. Reduction of the volume will invariably eliminate the howling effect.

"The quality is terrible, we cannot understand a thing that is said." This condition is known as distortion and is due to many factors. As a general rule, distortion occurs only in the audio-frequency circuits. Distortion may be caused by a defective tube, a defective battery, a defective loud speaker, a broken-down by-pass condenser across the output or, what is the most common cause of distortion, overloading of the tubes. A soft or gassy tube will cause distortion, but this defect in a tube is rarely encountered in standard makes of tubes. A weak or defective C battery is also a very common cause of distortion and will be evidenced by a tendency of the amplifiers to squeal. A "B" battery whose voltage has dropped 25 per cent. will often cause distortion and may be accompanied by a continuous high pitched squeal. Audio-frequency transformers of poor quality and design will cause distortion. This is generally indicated by the inability of the amplifiers to reproduce the extremely high and low musical tones. A transformer in which the leads have been soldered with a corrosive flux will cause distortion a short time prior to the time when the corrosive action of the flux causes the winding to open. Overloading of the amplifier tubes is evidenced by a blasting of the loud tones of the program. This is particularly true on local reception. The customer should be instructed to watch the overloading of the tubes and if the blasting does occur, he should detune his set slightly so as to reduce the volume to the point where the tubes will function properly. It is quite possible with the multi-tube sets used today, when installed in the vicinity of a powerful broadcasting station, to impress on the grid of the last tube in a series, sufficient voltage to swing the grid voltage beyond the limits of the straight line portion of the characteristic curve. Increasing the "C" battery potential or voltage on the amplifier tubes will tend to reduce this blasting. But this is not recommended as good practice because of the possibility of increasing the negative potential to such a point as to cause distortion when the tube is operating with normal volume. A great many amplifiers in receiving sets use a fixed condenser, ranging from the values of 0.002 to 0.006, connected across the loud speaker terminals. This condenser is known as a "by-pass"

condenser and is subjected in this part of the circuit to considerable peak voltages. Should this condenser fail, a distorted signal will result. If, on servicing, this condition is met and all the foregoing items have been checked with no results, replace this bi-pass condenser, as a potential breakdown in this condenser is rather difficult to test for unless laboratory equipment is available. Both these conditions call for the replacement of the transformers.

"It is loud enough, but very noisy. There is a continuous, cackling, rasping or scratching sound in the loud speaker." This may be the result of any one of many causes. Interference from either atmospheric or local sources is the most common cause of this defect. By local sources we refer to such apparatus as X-ray machines, violet-ray machines, electric railway systems, elevator controls, leaky power lines or transformers, automatic telephone switching lines, telegraph lines, and local telegraph stations in the vicinity of the receiver.

In checking noises in a radio receiver, the first problem should be to determine whether this is being picked up on the antenna or the loop, or whether it is originating in the set itself. In order to check this on a set employing an antenna, adjust the receiver to a point where the interference or noise is present. Then remove the antenna and ground connections from the receiver and note whether or not the noise ceases. If there is a great decrease in the volume of the noise when the leads are disconnected, it is safe to assume that the noise is emanating from an outside source.

If a loop set is employed, disconnect the loop and place a short length of wire, not over four inches in length, in place of the loop. If the noise ceases when the loop is removed, it may be safely assumed that the noise originates at some outside source. However, if the noise persists after the pick-up circuit, either loop or antenna, is removed, it is safe to assume that the noise is originating in the set itself. The noises referred to in the foregoing are those which are present at all times, particularly when none of the controls are being moved. Noises within the set itself may be caused by one of the following items:

A defective tube.

Dirty tube contact.

Defective battery.

Defective loud speaker.

Dirt on loud speaker diaphragm.

Defective battery contact or a loose connection.

The defective tube should be replaced by a tested one. The

tube contacts should be cleaned with a piece of emery cloth or fine sandpaper. Make sure to remove all traces of grit before replacing the tube. Make sure the contact springs of the sockets are clean and are making good contact to the contact pins of the tube. A defective battery will also cause many noises in a receiving set. The batteries should be checked in the following manner: Connect a pair of headphones across the outside terminals of each individual battery, and note the sound in the head phones. If there is a boiling or frying sound in the head phones when they are connected in this manner, it is an indication of a defective battery, and batteries showing such defects should not be used in a radio set. A loose or defective battery connection will also cause a set to be noisy. A loud speaker with a defective winding will also cause disagreeable noises. Dust and dirt accumulations on the loud speaker diaphragm will cause the set to appear noisy. A condition might arise where the diaphragm of the loud speaker becomes loosened, causing it to rattle when actuated by the incoming signal. Loud speaker defects generally necessitates a factory repair. A transformer winding which is deteriorating will cause a hissing or a frying sound in the amplifier. A loose connection in any part of the receiver, and the loud speaker, which is subject to vibration when the loud speaker is operating, will also cause the set to be noisy. In order to definitely locate the origin of noises in the receiver, use a pair of head phones and plug them in in place of the loud speaker. This will immediately determine whether the noise is originating in the loud speaker. If the noise persists with the phones plugged in the last stage of amplification, plug into the first stage, if a jack is provided, and repeat the process, plugging into the detector circuit. If but a single jack is provided, and this jack is connected in the output of the audio-frequency amplifiers in order to determine whether or not the noise is originating in the audio-frequency-amplifiers, connect the telephones in series with the detector "B" battery lead. In that way, you may determine whether or not the noise is originating ahead of the detector or in the audio-frequency amplifiers. Once the source of the noise is determined, it requires very careful checking of the various parts and connections in the circuits responsible.

"Set operates satisfactorily except when any of the controls are moved; it is very noisy." This condition indicates directly a defective connection caused by a mechanical failure. A defective tube will sometimes cause this condition, and is apparent when a rheostat is moved or the set is subjected to mechanical vibra-

tion. If the noise persists when any of the other controls are moved, such as condensers and coils, it is an indication that there is a mechanical failure which is causing a defective electrical connection. Dust and dirt accumulations on the condenser plates will cause noises to be heard when the condensers are rotated. The plates should be cleaned with an ordinary pipe cleaner. A bent condenser plate touching the opposite assembly will also cause this condition. Some variable condensers are constructed so that the electrical contact is made through a friction washer or through the friction of the rotor shaft to the bushing. This type of contact is quite satisfactory when the condenser is new, but after a long period of operation the parts wear, decreasing the friction, resulting in an indifferent contact which will at times cause the set to appear noisy, particularly so when the circuits of the receiver are tuned to resonance. Vernier drive shafts that have become worn through use will cause the sets to be noisy when the circuits are in resonance. Weak contacts in telephone jacks will also cause this condition.

"The signal is garbled. We cannot clear up the speech." This is generally caused by a defective oscillation control. Either a defective tube, a defective potentiometer or the neutralizing capacity out of adjustment will generally be found to be the direct cause. Of course, this applies only to receivers employing radio-frequency amplifiers ahead of the detector tube. If this condition is met in a single tube receiver it is generally due to the fact that such signal is too weak fully to actuate the detector tube. In the case of multi-stage radio-frequency amplifiers, this is a rather difficult problem to service. If it be caused by a defective tube, which it rarely is, then matters are simplified

The balanced or neutralized type of set employs neutralizing capacities for oscillation control. The so-called reflexes and untuned radio-frequency circuits use the potentiometer and in addition introduce losses in the radio-frequency transformers. Some of the straight tuned radio-frequency amplifiers employ a rheostat for each tube, some a single rheostat and a potentiometer; others a variable series resistance in the grid circuit of the first tube. There is another class that employs ingenious arrangements of wiring and parts to take advantage of stray capacities and interlocking stray fields, which have a tendency to prevent free oscillation. Certain other sets, it would appear, leave it entirely to chance and hope that it won't oscillate.

The sets in the latter two groups present very trying service problems.

The effect of this garbling condition is generally only apparent on extremely weak signals. It is generally impossible to eliminate entirely the whistle or carrier wave, and as a result, you receive a combination of voice or music, as the case may be, combined with the lower pitched tones of the carrier wave. Interchanging tubes in the radio-frequency sockets will sometimes lessen the tendency to oscillate, as there is some slight variation in the oscillating characteristics of the tubes, particularly after the tubes have been in operation for any length of time.

In the case of the failure of balanced or neutralized receivers, it is necessary to readjust the neutralizing capacities to their proper values. This particular service is rather difficult and should only be attempted as a last resort. It is not likely that these neutralizing capacities will vary a great deal from the original setting, unless the set has been abused or has been subject to physical damage. In the case of sets employing a potentiometer for oscillation control, this condition is extremely rare except when signals are received that are so weak that their modulated power is not sufficient to actuate the grid of the first tube in the series. It should always be remembered that a carrier wave of a broadcasting station is heard at a much greater distance from the station than is the audio-frequency modulation which is impressed on the wave. Sets employing individual tube control rarely have this trouble. The types of receivers using circuit arrangements and placements may be corrected by adjusting a single wire, but the problem is to find that wire. It is generally a grid wire and is, as a rule, oddly shaped and takes apparently a roundabout way to get where it belongs. Reducing the radio-frequency "B" battery voltage will help correct this condition.

The last type mentioned, where no apparent means are used to prevent oscillation, are generally found in very cheap sets, where the poor grade of material used introduces so many losses that it would be difficult to make them oscillate. Occasionally a set of this type oscillates and causes this condition and the only possible correction lies in tube interchanging and reduction of the radio-frequency "B" battery voltage.

"It is too loud on the loud speaker." This complaint is rare, but is sometimes heard. It is generally due to an effort to reduce the cost of the receiver, with the result that a telephone jack in the first stage of amplification is omitted, and for the same reason no provision is made for volume control. The only remedy for this condition is to reduce the voltage of the

audio-frequency amplifiers to a point where satisfactory volume is had.

"When I take my hand away from the set I loose the signal." This effect is known as a "body capacity" effect and is primarily due to poor design, a poor ground connection, or a poor circuit design. All sets should be equipped with grounded metallic shields. In addition, wherever possible, the shafts of the control knob should be electrically connected to this shield. If this is not possible, the low potential side of the various apparatus should be connected to the control knobs. Some sets have poor circuit design which prohibits the use of a grounded shield, and in cases of this kind, body capacity effects are quite disagreeable and persistent. Grounding of the "A" battery will sometimes be helpful in eliminating body capacity effects, but it should be first determined whether or not there is a connection between the ground terminal and the filament circuit within the set itself. For example, if the positive filament circuit is connected to the ground terminal, the "A" battery should be grounded at the positive terminal. If the ground terminal of the receiver is connected to the negative side of the filament circuit within the set, the negative terminal of the battery should be grounded. In sets of proper design in which shields have been incorporated and body capacity is present, we would suspect that the shield has become disconnected from the ground or battery circuit within the set.

"There is a frying sound in the set." This condition may be brought about by a defective battery, defective tube, a ground in the loud speaker, a defective battery connection, a transformer that is burning out or in the case of a set employing a gas type 200 detector tube, an excessive "B" voltage on this tube. The defective tube may be located by replacing the tubes with tested ones. The defective battery should be checked with head phones as described previously. A defective loud speaker may be tested by replacing same by head phones. All battery connections should be tightened. A defective transformer may be determined by a similar test that is used to locate a defective battery, except that a battery that is O.K. is used and connected in series with the telephones and the winding of the transformer under suspicion.

"When I touch the panel there is a ringing sound." This is invariably due to a microphonic tube and may be eliminated to a certain extent by interchanging the tubes until the best combination is had. The detector and audio-frequency amplifier tubes are the principal offenders in this connection. In sets

employing dry cell operated tubes such as the WD or WX11 or the UV or UX199, this condition is exaggerated unless the tube sockets are properly cushioned. There is a certain degree of this condition present in all receivers, even under normal conditions, and it is another reason why radio manufacturers are inclining more and more to the cushion type socket suspension

"There is a squealing sound in the set all the time." This condition may be caused by a defective tube, one that has become soft or gassy. It may be due also to a defective "B" or "C" battery that has dropped in voltage more than 25 per cent. A burned-out primary winding of a transformer, or an open telephone jack in the audio-frequency circuit will cause this squealing. Another cause may be the result is the heterodyning of two transmitting stations, or it may be the effect of a nearby receiver interfering with the one in use, however, under the last conditions the squeal will be present at certain definite places on the dial, whereas in the case of a defective battery, tube, transformer or jack, it is continuous throughout the entire scale reading.

"There is a buzzing sound like a motor boat. There is a clicking sound in it." This is a general indication of an open grid circuit. The frequency may vary from one click a minute to a very high pitched note. If the grid leak should become loosened from its clips, this sound will generally result. If a "C" battery is used, a poor connection or broken connection to this battery will give the same result. If none of these conditions appear to be the difficulty, it will be necessary to make a continuity test from the grid contact spring of each socket to the filament circuit.

"When I touch anything on the set a rattling sound sets up or the set will sometimes go dead and a jar will restore it." This is caused primarily by a loose connection either in one of the tubes or in the connection of the circuit. Investigation of every connection and friction contact in the set should be made. It is well to replace the tubes with tested ones in order to eliminate the tube as a factor. A loose shield or a loose venier shaft will give these results; particularly so when the circuit is tuned to resonance.

"It works in the detector jack, but does not operate in the first or second stages." If the A battery connections to the amplifier are properly made, this condition is probably due to a defective telephone jack in the detector circuit or a burned-out primary winding of the auto-frequency transformer connected in the detector circuit.

"It works in the first stage audio-frequency amplifier, but does not operate in the second stage." This is due to a similar reason

as previously given. It is caused by a defective telephone jack or transformer in the first audio-frequency circuit.

"The tubes fail to light." This condition may be brought about by a defective A battery, or a defective A battery connection. It may also be due to a faulty battery switch that fails to make proper contact. In the same way a rheostat that does not make proper contact will cause the same effect. Any loose connection in the A battery circuit of the set may cause failure of the tubes to light. If this condition exists only on one or two tubes, it is in all probability due to a burned-out filament. A dirty contact on the tube will sometimes cause the failure of a tube to light. If the contact springs of the socket do not make a firm contact to the tube pins, this condition might also occur. If dry cells are used, check to see that the individual cells are connected in the circuit with the proper polarity. If one or more of the cells are connected with reversed polarity, full voltage will not be had at the tube terminals.

In general, the service men should follow a procedure somewhat along these lines. Light the tubes and tune the receiver to the point where the best local station generally is received. Note the volume on the loud speaker, if one is used. If the volume is weak, tap the tubes with the finger-nail to determine whether or not the audio-frequency amplifiers are operating satisfactorily. If the amplifier is working satisfactorily, a ringing sound will be heard in the loud speaker. If this ringing does not result, check the polarity and voltage of the various batteries, and replace all defective ones. Inspect the connections of the batteries, and if this does not result in satisfactory reception, try replacing the tubes. If no sound at all results, immediately replace the loud speaker with the head phones to determine whether or not the loud speaker is defective. If no results are obtained, turn off the A battery switch and remove the tubes, and by means of a voltmeter, check the voltage between the filament and plate contact springs of each socket. If satisfactory indications are had and no signal is heard, repeat with a similar operation between the grid and filament contacts, using a pair of head phones in series with a 22½-volt battery in place of the voltmeter. Rather decided clicks should be heard, when contact is made in each instance with the exception of the detector grid. Because of the fact that in the detector circuit, a high resistance grid leak is used, the click will be rather weak. One of the foregoing tests will most probably check up the difficulty and the obvious repair should be made.

We will make a brief analysis of the various types of parts that are commonly used in radio broadcast receivers, as to their possible defects. The common practice in tuned radio-frequency circuits today, is to use the air-core type of transformer. These coils are generally wound on some form of tubing. Some manufacturers, depending on the adhesive quality of the binder to hold the wires in shape, do not use any type of tubing for support. These coils are generally wound with a relatively heavy wire, and are not subject to electrical failures. They may be connected into the circuit improperly, but as a unit are not subject to difficulties. Trouble is sometimes experienced with transformers of this type that have no supporting tubing, due to mechanical collapse. In some cases the windings may be wound on cardboard or fibre tubing, which has not been made impervious to moisture, and during the periods of humid weather these absorb enough moisture to cause high resistance short circuits of the winding.

Vario-couplers and variometers are constructed along the same lines, and are subject to similar defects. However, because of the fact that a vario-coupler or variometer has a moving element in it, some form of flexible connection is generally employed to bring out the connections of the moving coil. These flexible connections, because of mechanical movement, are subject to fracture. If no flexible connection is employed, and the contact is made through the friction of the rotor to a bushing on the stator, after long periods of use the friction may decrease, and reduce the effectiveness of the connection. These movable parts should be inspected for mechanical failure. The primary or fixed coil of the coupler is sometimes tapped, and leads taken off. Check to see that these leads are properly soldered, and not short-circuited or open.

A second type of radio-frequency transformer used is the so-called untuned transformer. This consists of a core of either iron or air around which is placed a bobbin with two inductively-coupled windings wound on it; one is primary and one is secondary. Because of the relatively low potentials and weak currents present in the radio-frequency circuits, they are not subject to failure to any great degree. Occasionally one will find a winding of one of these transformers burned out, but the per centage of such failures is rather small.

Audio-frequency transformers are similar in their general construction to radio-frequency transformers. The resistance of the primary winding is about 1,000 ohms, and the resistance of

the secondary is from 2 to 6,000 ohms. In order to get the required turns in a limited space the wire used is very fine. Because of the relatively high currents passing through these windings, they are more subject to failure than is the case with the radio frequency transformers. Failures generally occur at the point where the lead wire is soldered to the end of the winding. This is particularly true when a corrosive flux is used in soldering.

Transformers may be tested by measuring the resistance of the individual windings. A quick check may be had by connecting a 22½-volt battery to the windings and noting by the spark at the contact whether or not the circuit is continuous. Because of the high resistance of these windings a short circuit of the "B" battery will rarely cause a burn-out.

Variable condensers are, to our mind, the principal cause of trouble in a radio set. In this case it is particularly true that the troubles increase as the quality decreases. We have covered a good many points of possible failure and for that reason we will make but one addition. Most condensers use an oil or grease to reduce the friction in the bearings. This oil or grease, as the case may be, accumulates dirt and dust very rapidly and in condensers where the electrical contact is made through the friction of this bushing, these dirt and dust accumulations cause poor contact. Any moving part in a condenser that is not making a firm, clean contact will cause the set to be noisy when the circuits are in resonance.

In order to test for a short circuit in a variable condenser it is necessary to disconnect it from the circuit. The quickest test and the most satisfactory is to connect a source of 110 volts in a series with an electric lamp across the condenser. Rotate the condenser to its entire range and note the points of contact. Any short circuit will cause the lamp to light, and the exact point of short will be indicated by sparking.

Should the rotor assembly for any reason get out of alignment so much as to cause the rotor plates to touch the stator plates, it will be necessary to adjust the end thrust bushings so as to re-align the rotor assembly.

Fixed condensers of good quality rarely go bad or break down as the potentials generated in a radio receiver are as a rule far below the breakdown potential of the condensers. Cheap, fixed condensers, particularly those using fibre in their construction, are subject to climatic conditions and absorb moisture very readily. This causes high losses in the circuits in which the condenser is used. To test a fixed condenser it is generally necessary

to free it from the circuit, then connect a 90-volt B battery in series with a pair of head phones and make a contact across the terminals of the condenser. The first contact should cause a loud click to be heard. Remove the contact and count ten slowly, and make a second contact. If, on the second contact, little or no click is heard in the phones, such a condenser may be considered as perfect. If the second contact gives the same volume of click as the first contact, there is a high leakage in this condenser and it should be replaced. We might say in this connection that the contactors of the test just outlined should be properly insulated so that they do not come in contact with the hands or any part of the circuit. In testing a grid condenser it is necessary to remove the grid leak, as in most cases the grid leak is connected directly across the condenser, forming a permanent leakage path. The foregoing test is applicable to the testing of variable condensers and the same procedure may be followed. In making such a test the variable condenser should be set at maximum capacity.

Grid leaks are difficult to test without the necessary laboratory equipment and we would suggest that if there be any doubt in the service man's mind he should replace these.

Multi-point switches very seldom give electrical trouble, except when the tension of the contact spring weakens; this may cause a high-resistance contact. If the shaft of the switch is pigtailed, check the pigtail, making certain that it is intact.

Check also the soldered connections to the contact points of the switch, making sure that the contact connections are firm and clean.

Telephone jacks, filament control jacks, and battery switches constructed along the lines of a telephone jack are often sources of trouble. The contact springs may become weakened and dust and dirt accumulate on the contact points causing the failure of the jacks or switch, as the case may be, to close the necessary circuits. Faulty jacks are the cause of a large percentage of the failure of amplifiers to operate properly. To check these, plug the telephones in and out of the jack very slowly and observe just how the springs should function. If the springs do not close the circuits as they should, bend the offending spring down or up as required to insure firm contact. It would be well to draw a fine piece of emery cloth across the contact points to brighten them up.

The principal difficulty which may be experienced with rheostats is that due to a faulty contact between the contact and the resistance winding. Burn-outs of the rheostat are very rare.

Potentiometers are subject to the same difficulty in the matter of contact as is the rheostat. In making any adjustments on receivers in which a potentiometer is used, it is well to set the potentiometer at the half-way mark while making these adjustments. Potentiometers are subject to burn-outs. To check for a burn-out, place a pair of head phones in series with a battery and connect one side of this test lead to the center terminal to the potentiometer which is generally connected to the contact arm. Place the contact arm at the center of the winding and make contact to each of the other binding posts in turn.

Binding posts sometines cause trouble due to loosening of the screws. All binding-post screws should therefore be tried and if found loose, should be firmly seated.

Crystal detectors, which are used principally today in the so-called reflex type of circuit, sometimes fail because of dirt accumulations on the surface of the crystal. Occasionally the crystal may be burned out by an accidental short circuit. To restore a dirty crystal, use a non-alkaline soap and a tooth brush. Scrub the surface of the crystal thoroughly and rinse in cold water, removing all traces of soap.

In this connection we might say that considerable service is experienced on reflex sets that fail to give results, and the crystal is generally found to be the cause. Fixed crystals are not entirely satisfactory.

The foregoing is a brief review of some of the most frequent troubles that may occur in the radio receiver. There may be a few troubles that apply to a single type of receiver which have been omitted, but such will be characteristic of that particular type. In conclusion, we would repeat: Test all sets before sale and be truthful in the matter of results that may be expected. Do not lead the customer to believe that he will be able to receive California any time he desires. Advise him also of the probable length of life of his batteries. To the service man: ask questions and analyze the defects before you commence operations. A few judicious questions will oftimes save considerable work and create a more favorable impression with the customer.

PROCEEDINGS OF
The Institute of Radio Engineers

Volume 14 OCTOBER, 1926 Number 5

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GENERAL INFORMATION

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings and at the Sections in the several cities listed on the following page.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership.

Subscriptions to the Proceedings are received from non-members at the rate of \$1.50 per copy or \$9.00 per year. To foreign countries the rates are \$1.60 per copy or \$9.60 per year. A discount of 25 per cent is allowed to libraries and booksellers.

It is understood that the statements and opinions given in the Proceedings are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

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INSTITUTE ACTIVITIES

September Board Meeting

At the September 1st Board meeting held at Institute headquarters, New York, the following were present: D. McNicol, president; R. Bown, vice-president; L. Espenschied, M. Eastham, A. N. Goldsmith, A. H. Grebe, R. H. Marriott, L. A. Hazeltine, L. E. Whittemore and A. E. Reoch.

The Board approved election to Associate grade of 179 applicants and to Junior grade 29. The following were approved for transfer to Member grade: O. K. Hovgaard, D. H. DeBurgh, H. W. Kitchin, James A. Dowie, A. A. Hebert, E. H. Smythe, R. K. Potter, R. H. Wood and N. E. Wunderlich. The following were approved for direct election to Member grade: T. Thorne Baker, Irving Vermilya, and J. B. Dow. F. A. Hinners was transferred to grade of Fellow.

The Liebmann Memorial Prize, consisting of $500 in cash, which is issued annually was this year awarded to Dr. Ralph Bown for his researches in "Wave Transmission Phenomena." The award will be presented to Dr. Bown at the annual convention early in 1927.

The addition of about 500 square feet of space for headquarters offices was approved by the Board.

The president was authorized to appoint a committee on Broadcast Engineering. This committee will consist of five members, three of them to be board members. The personnel of this committee will be announced in the next issue of the PROCEEDINGS.

There was preliminary discussion relative to the holding of the Annual Convention in 1927. A Convention Committee will be appointed at the October Board meeting. The Convention very likely will be held in January.

Rochester Section

The Rochester Section will hold a meeting on October 2nd at which Mr. John W. Million, Jr., of the King-Hinners Company, will deliver a talk on radio.

Membership Committee

The Membership Committee, H. F. Dart, chairman, held a meeting at Institute headquarters on the evening of September 7th. The Committee is planning a campaign for new and desirable members. The desire is to do all possible to make sure that every radio man may have an opportunity to make application for membership. Ordinarily, it is best even for experienced radio engineers to apply for Associate membership initially. After being admitted to the Institute, those enrolled as Associates, are in a position to study the requirements for the higher grades and to become acquainted with the required number of Fellows and Members so that they may use the names of these gentlemen as references.

Washington, D. C., Section

The new Section officers for the coming year are: Chairman, A. Hoyt Taylor; Secretary-Treasurer, F. P. Guthrie, 1112 Connecticut Ave., N. W., Washington. The Section officers are working on a schedule of important radio papers to be presented and discussed at meetings to be held during the next Fall and Winter months.

Chicago Section

The Chicago Section held a meeting on Friday, July 30th, in the rooms of the Western Society of Engineers. A paper was presented by Dr. E. W. Engle on the subject of "Characteristics of Electrolytic Rectifiers as Used in Radio Engineering."

A committee was appointed to serve as an Executive Committee, the members being G. A. Johnstone, three years; J. H. Miller, two years, and Montford Morrison, one year. These members will serve with the chairman of the Section.

Toronto Section

The officers of the Toronto Section to serve during the coming year are: D. Hepburn, Chairman; C. C. Meredith, Secretary; George F. Eaton, Vice-Chairman; C. I. Soucy, Assistant Secretary, and A. L. Ainsworth, Treasurer. Professor T. R. Rosebrugh was elected Honorary Chairman of the Section.

Diplomas for Fellows and Members

The diplomas authorized to be issued to Fellows and Members of the Institute are ready for distribution. Fellows and

Members who have not yet procured their diplomas may do so by making application to the Secretary.

Change of Address

Members, any grade, who change their place of employment or their residence address should advise the Secretary of the Institute relative to the new address. This is important in order that the PROCEEDINGS and other publications of the Institute may reach each member promptly and without being returned to Institute headquarters for remailing.

The 1927 Year Book, which will contain the names of all members, all grades, in good standing after the beginning of the year, is intended to be correct in all particulars. Members should notify the Secretary's office as to correct business connections and correct mailing address so that entries in the Year Book may be accurate.

Pictures of the Presidents

The Institute has procured and had framed pictures of all the past presidents of the Institute. These are displayed in one of the rooms at Institute headquarters.

Los Angeles Section

The Los Angeles Section at its last meeting had for consideration a paper on the subject of "Radio Interference," by Ralph W. Wright.

The officers of the Los Angeles Section are: Chairman, Lee Yount, 1220 Wall Street, Los Angeles, Calif.; Vice-Chairman, M. E. McCreery; Secretary-Treasurer, L. Elden Smith, 340 North Painter Ave., Whittier, Calif. The Executive Committee is made up of the officers and Les Taufenback, Dr. E. C. Waters and C. S. Pratt.

Advertising in the PROCEEDINGS

Members of the Institute in writing to the manufacturers of radio apparatus who advertise in our pages should not fail to mention that the advertisement was seen in the PROCEEDINGS. The Institute's income from advertising is used to help defray the cost of publishing the PROCEEDINGS. All possible support should be given to the concerns which advertise in these pages.

Entrance Fee

On page 15 of the 1926 Year Book, Article IV, Dues, the entrance fee payable on admission to the Institute, covering each grade is given. During the past three or four years the entrance fee has been waived, but is to be restored on January 1, 1927, as stated in Article IV. Those who join the Institute, any grade, after January 1, 1927, shall be required to pay the proper entrance fee, as well as the annual dues, as soon as they are notified of their election to membership.

PROCEEDINGS to be Issued Monthly

The present plan is to begin monthly publication of the PROCEEDINGS, beginning with the January, 1927 issue. All members will receive the monthly issues as heretofore they have received the bi-monthly issues, without any additional dues payment. This increase in the number of copies of the PROCEEDINGS, which members receive annually, will be of very great advantage and value.

Bound Volumes of the PROCEEDINGS

Bound volumes of the PROCEEDINGS are available from the year 1917 to 1925, inclusive. The price to members is $8.75 per volume. The price to non-members is $11.00 per volume.

Chicago Section

The new officers of the Chicago Section elected at the annual meeting held on July 30th, are: Chairman, G. M. Wilcox, Professor of Physics, Armour Institute; Secretary-Treasurer, H. E. Kranz, 703 North 5th Ave., Maywood, Ill. As stated in another paragraph in this issue, the officers for the year act with an Executive Committee which carries over from year to year in managing the affairs of the Section.

Membership

On August 1, 1926, the Institute had a membership enrollment as follows: Fellows, 80; Members, 415; Associates, 2,760; Juniors, 175—a total of 3,430. This is a gain of approximately 1,000 in the past year.

In the British Isles there are 255 members; in Canada, 135; n other foreign countries, 220.

Section Territories

Philadelphia—Philadelphia, Camden, Atlantic City.

Washington—District of Columbia, Annapolis.

Boston—60-mile radius.

Chicago—Chicago City, Aurora, Joliet, Ottawa, Elgin.

Toronto—Province of Ontario.

Rochester—Syracuse, Elmira, Oswego, Binghamton.

Seattle—State of Washington.

San Francisco—Oakland, Alameda, San Jose, Stockton, Sacramento, San Rafael.

Los Angeles—Santa Barbara, Pasadena, San Diego, San Pedro, Bakersfield.

Errata

In the paper by N. N. Tsiklinsky and V. A. Volynkin on "Choice of Power for a Radio Station," published in the PROCEEDINGS for June, the following changes should be noted:

Page 383, equation (2), e should be ϵ; equation (3), the exponent ξ should be δ.

Page 384, second equation, C should be $\mathscr{C}$; in formula (5a), A_{mA} should be a_{mA}; in formula (6a), C_{mA} should be $\mathscr{C}_{mA}$; eighth line from top, exponent -7 is inverted; in formula (4a), C should be $\mathscr{C}$.

Page 385, 13th line, consideron should be consideration.

Page 386, 10th line from bottom $\gg$ should be $\not>$.

Page 388, last line, power kw. should be power 20 kw.

Page 389, 5th line of summary, h^2 should be h^{-2}.

REDUCTION OF INTERFERENCE IN BROADCAST RECEPTION*

By

ALFRED N. GOLDSMITH

(CHIEF BROADCAST ENGINEER, RADIO CORPORATION OF AMERICA)

When, in addition to the desired program, there is released from the loud speaker of the receiving set employed by the broadcast listener a program or programs emanating from other and undesired stations, it is said that "interference" is present. The relative loudness of the interfering sound, as compared to that of the chosen program, will in part determine the usefulness of the radio receiver to its owner (at that time and for the rendition of the desired program). If the interference is extremely slight, it may be tolerable; yet if it is at all noticeable, even during silent pauses in the desired program, it will probably detract from the enjoyment of the listener to such an extent as to spoil his entertainment and the corresponding value of the radio broadcast service. High quality radio service requires inaudible (that is, psychologically non-existent) interference.

The discussion in this paper will be limited to interference caused by undesired broadcasting stations; although it should be kept in mind that the interference from damped wave marine transmitters (for example, of the spark type), harmonics of continuous wave transmitters or irregular variations in their radiation (such as "arc mush"), inductive interference from a number of electrical devices and systems, incidental to human activities, and electrical disturbances of atmospheric origin may all interfere with broadcast reception of feeble signals to a noticeable extent. The reduction of interference primarily involves technical factors, but it also carries the engineer and investigator into the realm of human relations. It is accordingly necessary in the following study of the reduction of interference to consider, as a practical proposition, certain non-technical matters.

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1. Factors in the Production of Interference

It is assumed that reception is being carried out, at a given frequency, using a vertical effectively non-directional antenna. It is also assumed that the incoming electromagnetic waves, carrying the broadcast program, are vertically polarized. It is also taken for granted (although unfortunately it is not universally the case in practice) that the frequencies of stations on adjacent channels are separated by 10 kilocycles per second and that, in consequence, their carrier waves will produce a practically inaudible beat-note with one another. It is to be noted, however, that the intelligence-carrying side bands of two signals will interfere with each other under such conditions unless the audio frequencies transmitted as carrier modulation from each station are limited to a maximum of 5,000 cycles per second, a value too low for entirely satisfactory reproduction of music or speech.

(*a*) *Field Strength.* The more intense or powerful the field of the incoming waves, the greater will be their capabilities in the production of interference. It is therefore to be expected that persons in the immediate vicinity of powerful broadcasting stations, which are capable of laying down high field strengths over considerable areas, may experience interference.

(*b*) *Receiver Selectivity.* Selectivity is that characteristic of a receiver which enables it to discriminate between two incoming signals on neighboring frequencies, passing one and excluding the other. It involves a progressively increasing attenuation of the radio frequency (or intermediate frequency), tuning system toward frequencies increasingly removed from the desired signal frequency.

It should be noted in this connection that the sensitivity of a receiver will apparently influence its working selectivity. Highly sensitive receivers, which give extremely powerful sounds from the loud speaker when actuated by feeble incoming waves, will correspondingly give an audible response from an interfering signal under circumstances in which a less sensitive receiver, while giving a weaker loud speaker sound, will not seem to produce any interfering signal because the interfering signal has been dropped below the audibility limit. The obvious remedy for interference which accompanies excessively loud signals from weak stations, produced by an ultra-sensitive receiver, is to reduce the receiver sensitivity by volume control manipulation (assuming that the selectivity of the receiver is independent of its sensitivity, which is sometimes not the case).

Of analogous nature is the interference resulting from the use of an antenna or pick-up system of excessive dimensions whereby an inappropriately large signal voltage is impressed upon the receiver, perhaps overloading one or more stages of amplifier tubes. Under such circumstances, even feeble interfering signal voltages will cause an audible response in the loud speaker, and normal signal voltages will cause undesirably loud or distorted signals. In this case the indicated remedy is a reduction in the size of the wave pick-up system.

It is clear that the practical usefulness of feebly selective receivers is limited to locations where there are only weak signals, on considerably separated frequencies. Such signals from distant or low-power stations are generally found exclusively in rural districts under present broadcasting conditions.

By contrast, highly selective receivers have a wider (and in fact, practically universal) sphere of usefulness. They are capable of receiving weak signals from comparatively distant low-power stations without interference even though there are nearby powerful stations in operation.

(c) *Psychological Influences.* Interference is astonishingly odious to the average broadcast listener despite the absence of direct financial participation by him in the expense activities of the broadcasting stations which attempt to serve him. A listener may receive eleven stations perfectly, but fail to receive the twelfth because of interference from a thirteenth station. Under these circumstances, the listener-reaction in the extreme case is somewhat as follows: The eleven stations which he can receive become uninteresting to him, and are neglected. The twelfth station which he cannot receive, regardless of its intrinsic merits, becomes the grimly desired goal of his radio ambitions. The thirteenth, or interfering station, also regardless of its program merits and tone quality, appears to him as the serpent in what would otherwise be a radio paradise and, unless restrained, he will bruise the head of serpent beneath his heel.

It is also found that the designation given to a broadcasting station makes a great difference to many listeners. The following, for example, is fairly typical: A listener will be located a mile from a one-half kilowatt station, or perhaps three miles from a 5-kilowatt station. He will experience a certain amount of interference due to the high field strength of the incoming waves, but, since the stations in question seem to be sanctioned by time-honored custom, it will never occur to him to complain of their existence. Other listeners, located say ten miles from a 50-kilo-

watt station, and experiencing no greater field strengths than the uncomplaining listener just mentioned, will learn to their astonishment that they are only ten miles from a "super-power station." They may then experience psychological as well as physical interference, and some will protest. Unfortunately field strength is not the sole determinant of public satisfaction.

One may also briefly touch on the possible misinterpretation of the purpose of a newly established broadcasting station of considerable power. Radio is a new and complicated art, imperfectly understood by the public; and it is a simple matter for the good people of the locality in which an efficient broadcasting station has been established somehow to get the opinion that there is some objectionable motive responsible for the establishment of the station in question. In common with other important elements in broadcasting (censorship, copyright privileges, wave length allocations, operating time, and the like), the location and power of broadcasting stations have controversial aspects.

2. Analysis of Receiver Selectivity

(*a*) *Basis of Selectivity.* Essentially all present-day receivers depend for their selectivity on a well-known characteristic of a circuit (or circuits) containing inductance and capacity. Such a circuit shows a minimum reactance (or impedance) at a certain specified frequency, to which frequency it is said to be "tuned." Maxima of voltage or current may be produced in this circuit at this frequency. The reactance of the tuned circuit is greater at frequencies above or below the frequency to which it is tuned, and the increased impedance of the circuit results in a larger attenuation of currents at off-tune, or undesired frequencies. This simple circuit still forms the basis of modern receiver selectivity.

(*b*) *Improved Selectivity.* In general, the selectivity of a single tuned circuit is insufficient to meet existing broadcast interference problems. While the current response, produced by a given voltage, at an undesired frequency is less than that at a nearby desired frequency, yet the ratio of the undesired current to the desired current is often not so small as is necessary to reduce interference to inaudibility. Among the methods which may be employed in practice to increase the selectivity of the receiver are the following:

(*b*-1) A succession of tuned circuits may be coupled to each other, and the desired signal energy, as well as the undesired signal energy may be caused to traverse the successive circuits.

The attenuation toward off-tune currents may be considerably increased in this fashion, and the selectivity improved.

(*b*-2) The incoming signals, both desired and undesired, may be caused to pass through a sequence of tuned circuits each of which is more or less independent of the preceding. Generally such circuits are electrically separated by one-way repeaters of the triode type. It is attempted to reduce the back coupling between successive circuits to a negligible quantity, and this requires in general the neutralization of the effects of inter-electrode capacity in the triode, as well as the choice of suitable geometrical configuration for the tuning elements in the successive circuits, and also the adoption of certain other expedients. As an ideal, the attenuation toward off-tune currents in a succession of such independent circuits is a summation of the attenuations due to each one of the circuits, so that the over-all selectivity of such systems may reach high values.

(*b*-3) An intermediate frequency selectivity may be utilized, generally in addition to radio frequency selectivity secured according to the preceding methods. This is accomplished in the super-heterodyne receivers. The incoming desired wave is converted to a fixed intermediate frequency by heterodyning with a tunable local oscillator. In the reception of speech or music, a super-audible intermediate frequency is employed. The converted or intermediate frequency is then generally passed through correspondingly tuned amplifiers. Undesired waves are converted to frequencies which are highly attenuated by the intermediate frequency circuits. In view of the considerable ratio of the incoming radio frequency to the intermediate frequency (about 25-to-1 in ordinary broadcast receivers), an unusually sharp cut-off of currents at undesired frequencies close to the desired signal is obtainable.

(*c*) *Necessary Limitation of Selectivity.* Although the opposite is well known to radio engineers, there has been a widespread public impression that the selectivity of receivers may be indefinitely increased, and that interference can therefore be eliminated by the use of sufficiently selective receivers.

Considering first the ideal case, it may be assumed that the transmission from a radio telephone station of high quality will include the carrier frequency and two side bands extending to frequencies 10 kilocycles above and below the carrier frequency. Such a transmission therefore occupies 20 kilocycles, which is the proper width for a radio channel. Adjacent carrier frequencies should, therefore, be separated by 20 kilocycles. Unfortunately,

the urgent pressure applied by prospective broadcasters has necessitated the assignment of broadcasting frequencies only 10 kilocycles apart. At best such a system is a compromise. Under such a regime, however, a receiver should admit, without attenuation, a band of frequencies 10 kilocycles wide. For example, when tuned to 660 kilocycles, all frequencies from 655 to 665 kilocycles should be equally passed through the receiver, whereas all frequencies outside of this band should be weakened to inaudibility even if the external field strength corresponding to them is considerable. The transmission band of such a receiver, being flat-topped, and having sharp cut-offs, will permit reception without quality distortion at audio frequencies (assuming a suitable audio frequency detector, amplifying system, and loud speaker).

Actual receivers do not behave in this fashion. Their admittance curve is sharply peaked in many cases, and their cut-off gradual. As a result, tone quality is injured by selective attenuation within the side bands, and interference from stations on neighboring frequencies is admitted. Without going into further details, it may be stated that the further a receiver deviates from the flat-top and abrupt cut-off admission band, the less desirable it is from the standpoint of selectivity and tone quality. As an obvious secondary consequence, the useable selectivity of receivers is definitely limited.

3. Performance of Present Day Transmitters and Receivers

It has not yet proved feasible to employ, for broadcasting purposes, transmitters emitting a single side band, the other side band and the carrier being eliminated. Nor has multiple transmission (of the same program) on an identical frequency at each of a number of interconnected stations become a part of standardized broadcasting practice. Both of these systems have been experimentally tried, and their practical capabilities will no doubt be determined by further trial. For the present, however, they need not be considered.

(*a*) *Transmitter Power.* The power of transmitting sets for broadcasting purposes varies over the wide range of 10,000-to-1. A number of midget transmitters of 5 watts are employed for purely local transmission, and a number of 50-watt sets are also in use to cover certain limited areas. The reliable service range of such transmitters, is, however, too limited for serious consideration in dealing with broadcasting problems of national scope.

It has long been the contention of far-sighted radio engineers

that the only range of transmitters deserving real weight is the true "service range." Quantitatively, we cannot exactly define the service range of transmitters because of the somewhat irregular nature of radio transmission. However, a rough idea of what is meant can be gained from the tentative definition that "the service range of a transmitting station is that distance, over which it will produce, by day or night and at all seasons of the year (except during unusually severe atmospheric disturbances), a signal having at least as great a ratio to all disturbing sounds as the music from a high quality phonograph on a well-cut new record bears to the incidental needle scratch."

The basis of this definition is the acceptance by the public of high-quality phonographic reproduction as a service of human value. It is to be noted that this type of reproduction is taken as marking a minimum or lower limit of acceptability for radio signals received within the service range. A radio signal which is not so "clean" as the output of a good phonograph is received at a point outside of the service range of the corresponding transmitting station for critical listeners.

To persons accustomed to the ranges secured by professional radio operators and amateurs, with telegraph signals, and under favorable conditions, the limited service ranges secured by broadcasting stations of a given power will come as a shock. It must be remembered that broadcasting stations communicate *telephonically*. An artistic effect is to be produced, and interference which can be overlooked in telegraphic reception of commercial material would be fatal to the enjoyment of the broadcast listener. Then too, the manipulation of receivers by the public is less skilled than that of the professional radio telegraph operators. Loud speaker operation is demanded in broadcasting in many instances, and extraneous sounds and disturbances in the same room require the loud speaker to deliver an unusually clear and loud signal for satisfactory results.

For these reasons the service range of stations of various powers in the eastern portion of the United States may be estimated as follows:

TABLE 1

Antenna Power	Service Range
5 watts	1 mile
50 watts	3 miles
500 watts	10 miles
5,000 watts (5 kilowatts)	30 miles
50,000 watts (50 kilowatts)	100 miles

These figures are primarily based on analysis of reception data by the Bureau of Standards of the Department of Commerce, and published statements of Secretary of Commerce, Herbert Hoover.

Of course these service ranges will be considerably exceeded many times under favorable conditions. On the other hand, at some points within the service range area where local conditions happen to be unusually unfavorable, good service will not be secured. A typical cause for poor reception in a limited zone, within the general service area, is the radio shadow cast by great masses of steel buildings.

(*b*) *Field Strengths.* The field strengths required for satisfactory broadcasting reception, within the service range, are far beyond those which have been regarded as commercially necessary in marine and transoceanic radio telegraphy, and for the reasons given in the previous discussion. The following table gives a general idea of the type of service, in its relation to disturbing sounds, which is yielded by various field strengths of waves within the broadcasting band:

TABLE 2

Signal Field Strength	Nature of Service
0.1 millivolt per meter.................	Poor Service
1. millivolts per meter.................	Fair Service
10. millivolts per meter.................	Very Good Service
100. millivolts per meter.................	Excellent Service
1,000. millivolts per meter.................	Extremely Strong

The field strength corresponding to the outer boundary of the "service range" lies between 1. and 10. millivolts per meter and, in general, is nearer the latter value than the former.

The clear and outstanding conclusion from an analysis of these figures is that it is necessary, in a large country like the United States with its great rural areas, to have stations which can lay down field strengths in excess of 1. millivolt per meter over great areas. Every device of human utility has passed from the play-toy stage into the stage of reliable service. In terms of broadcasting, this means that field strengths of the order of tenths of a millivolt per meter, despite their sporting fascination to some people, will play little part in the future development of broadcasting. Conversely, it means that field strengths of the order of tens of millivolts per meter represent the goal of service for broadcasting of the future.

(c) *Receiver Classification and Performance.* The great majority of receivers now used for broadcast reception fall into the following classes, which are arranged in order of increasing selectivity:

Receivers employing a single radio-frequency tuning stage, generally with adjustable regeneration.

Receivers employing three radio-frequency tuning stages, each stage being fairly heavily damped and without effective neutralization of coupling between stages of radio-frequency amplification.

Receivers utilizing three radio-frequency tuning stages, generally of low damping, and with more or less complete neutralization of interstage couplings.

Receivers utilizing one or more intermediate-frequency tuning stages, and one or more radio-frequency tuning stages.

The typical performance of some of the above receivers is given, approximately, in the following table. It is assumed that the receiver is tuned to 660 kilocycles (455 meters) and that the voltage reaching the final detector grid from a given signal, corresponding to satisfactory volume in a loud speaker attached at the end of the audio frequency amplifier, is measured. An equal signal voltage is then applied to the receiving set, but at a frequency of 670 kilocycles, or 10 kilocycles off the desired signal frequency. The ratio of the voltage produced by the desired signal to that produced by the undesired signal, at the detector grid in this case, is given in the second column of the table. If the undesired signal is 710 kilocycles, or 50 kilocycles removed from the desired signal frequency, the corresponding voltage ratios of desired to undesired signal at the detector grid, are given in the third column of the table. It must be remembered that individual receivers vary in this regard, and that the following values represent order of magnitude only in each case:

TABLE 3
VOLTAGE RATIOS AT DETECTOR GRID

Type of Receiver	10 kilocycles off carrier	50 kilocycles off carrier
One Radio-frequency Stage...........	1.5	5.5
Same, but with Regeneration	18.	60.
Three Neutralized Radio-frequency Stages..........................	15.	8000.
One Radio-frequency and two Intermediate-frequency Stages (Superheterodyne)....................	800.	over 10000.

It is obvious that suitable tuned circuits have the same functional importance in receivers as red corpuscles have in the blood. On this basis it is found that some of the simpler receivers are suffering severely from pernicious electrical anemia. Their present debilitated condition results from their failure to meet the stringent broadcasting conditions of today, however placid and useful may have been their existence in the pioneer period of broadcasting.

It is clear that there are possibilities of trouble from interference in a district where owners of receivers using a single radio-frequency tuning stage have become accustomed to receive distant signals from weak stations fairly well, but where receiving conditions are altered by the establishment in that district of a powerful transmitting station. Receiving sets which have been getting signals of the order of 0.5 millivolt per meter, will then have impressed upon them signals of the order of 100 millivolts per meter. The unsuitability of such receivers for modern broadcasting conditions will be glaringly displayed, and listener dissatisfaction results. Yet radio progress, as pointed out in the previous discussion, depends upon the production of higher field strengths from broadcasting stations of increased power, whereby real service can be given to large areas.

In the case of the establishment of the Bound Brook station, it was found that the great majority of complaints came from owners of home-made sets. Few complaints were received from owners of factory-made sets, except those of the single radio-frequency tuning stage variety, and of the three highly damped radio-frequency tuning stage type. The detailed data on this point will be analyzed in another portion of this paper.

4. The Bound Brook, New Jersey, Experimental Broadcasting Station

When it became evident to the executives and engineers involved that the next major forward step in broadcasting involved the establishment of a high power broadcasting station, careful preliminary studies were made of the anticipated performance of a 50-kilowatt transmitter located in the neighborhood of New York City. Numerous apparently suitable sites were selected, and the field strength distribution around a station located at each of these sites and at various distances from the station was calculated and plotted in map form. It was found that many important conditions had to be met by any location to be finally selected as suitable. These conditions will not be given in this

paper since they will appear in a forthcoming Institute paper.*

Ostensibly cooperative persons kindly suggested that the station be located at the tip of Montauk Point, Long Island, on a remote lightship, on the highest and most inaccessible peak of the Alleghany Mountains, or even on an anchored balloon high in the air. Suffice it to say that unsympathetic engineers did not regard these proposals as feasible either technically or economically.

The most desirable location for the station having been predetermined to be near Bound Brook, the station was built and placed in experimental operation for a week early in November, 1925. After certain modifications in the equipment had been completed it was again placed in experimental operation early in December, 1925, and has been transmitting since that time under the call letters 2XAR or WJZ.

As soon as the station had been in operation for a few days it was found that some interference was being created in a region which we may term the "interference area"—a roughly circular region centering on Bound Brook.

5. Establishment and Procedure of Interference Reduction Service

It was obvious to the engineers that the interference complained of could be reduced to negligible dimensions by suitable technical expedients. So far as is known, in every other case where a broadcasting station has been established, the listeners in that locality have in the main been permitted to discover for themselves how to eliminate the resulting interference. The managements of broadcasting stations have felt, perhaps properly, that their functions do not include educational campaigns on receiver construction and performance. However, it was believed that a demonstration of the usefulness of high power broadcasting was of such fundamental importance to the radio art that the management of the Bound Brook station was justified in going to unusual lengths in assisting the listeners who experienced difficulty in eliminating interference from that station, in order that practically the entire listener-community might be satisfied with the performance of the station. The causes of the interference, their correlation with receiver types, and the desirability of getting, at first hand, a cross-section of

*J. Weinberger, "The High Power Broadcasting Station of the Radio Corporation of America, at Bound Brook, New Jersey."

receiving conditions in 1925 and 1926 also were factors which led to the establishment of a special service for the benefit of the local listeners.

A qualified radio engineer, Mr. Bronson S. McCutchen, of Plainfield, New Jersey, was retained to direct the activities of sixteen skilled assistants who were suitably located in towns within the "interference area." These gentlemen were available to call on each complainant and, through actual demonstration, to prove to him that the interference could be reduced or eliminated by a suitable and simple addition of equipment to the existing receivers. No charge was made for this service to the listeners, nor was any equipment sold by the Radio Corporation of America or its representatives. The entire costs of the interference reduction service were borne by the Radio Corporation. In Appendix A, the geographical organization of the staff is given. At this point, I wish to express my appreciation of the intelligent way in which the gentlemen involved carried out their duties.

Copies of all complaints received by the Department of Commerce were forwarded to the representatives of station WJZ, and this cooperation by the Department was extremely helpful. These complaints, together with those received by the station directly, were then handled in accordance with the following routine:

(*a*) A pamphlet entitled, "Reducing Interference from a Near-by Broadcasting Station of High Power" was at once mailed to the complainant. Pertinent excerpts of this pamphlet, showing the recommended methods, are given in Appendix B. While elementary, this material is included because it may be of help to other station executives facing similar problems. The simplicity and inexpensiveness of the recommended methods are obvious. The methods described in the pamphlet, as well as similar methods, also received wide publicity through the cooperation of the radio editors of local newspapers.

(*b*) The interference reduction service telephoned the complainant shortly thereafter to determine whether the trouble still existed or whether it had been cleared by the complainant himself using the methods recommended in the pamphlet or by other methods. This avoided unnecessary visits to persons no longer experiencing interference. It was also necessary to telephone in advance because of the difficulty in making night appointments with the listeners.

(*c*) If the interference still existed, a call was made by a member of the interference reduction service who determined the

best method of eliminating the interference. After demonstration of this method to the listener, he was invited voluntarily to fill out and sign a blank stating his opinion of the results obtained. It was hoped to gather valuable statistical data from these blanks, a typical one of which is reproduced in Appendix C.

The results of these activities were extremely gratifying. Although an unusually severe winter rendered the New Jersey roads almost impassable for considerable periods during December, 1925, and January and February, 1926, thus rendering visits to complainants very arduous, the number of complaints on hand never became so great as to be unmanageable. In Figure 1

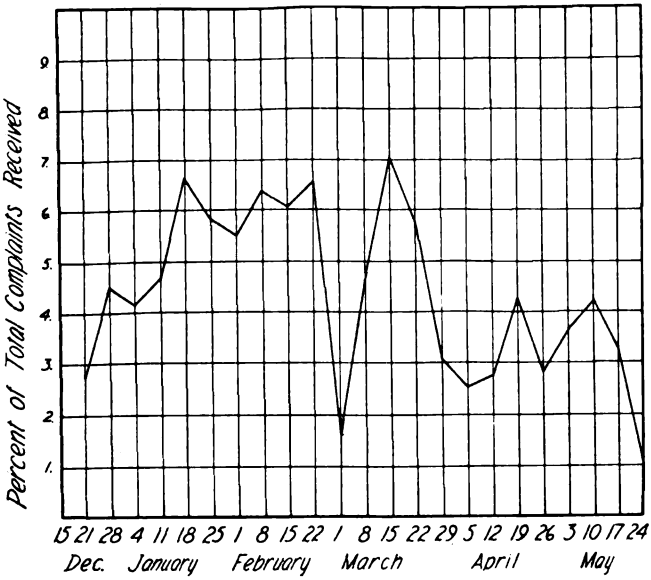

FIGURE 1

are given the percentages of the total complaints received each week for a total of 23 weeks from December 15, 1925, to May 24, 1926. The complaints built up rapidly after the first week of December, 1925, when the station began program transmission. About 6 per cent of the total complaints were then received per week during January, February, and March, 1926. During April and early May, 1926, about 3.5 per cent were received per week, constituting an appreciable reduction. Thereafter the complaints practically disappeared. During June and July, 1926, complaints were received at the low rate of one every week or two. A classification of the relative proportions of the various methods

whereby the complaints were cleared will be given at the end of this paper.

It is interesting to note that this work constitutes in all likelihood the most extended systematic interference study so far carried out in the homes of the listeners.

6. Statistical Data on Broadcast Station Interference

As pointed out in Section 1 of this paper, the primary factors in interference with broadcast reception are field strength, receiver selectivity, and certain psychological influences. The results of the interference reduction service activities have been systematically tabulated in such a way as to enable an analysis of the effect of these different factors.*

(*a*) *Dependence of Complaints on Field Strength.* The complaints received were first classified, using percentage of total complaints against field strength at the corresponding receiving stations. The results are given graphically in Figure 2. The

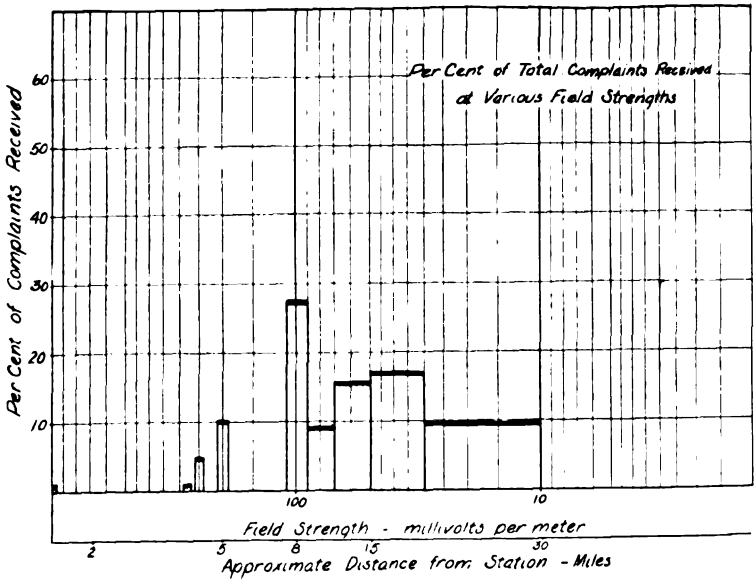

Figure 2

approximate distances from the station are also plotted along the ordinate axis as well as the field strengths.

The average density of population within 6 or 8 miles of the

*For which I desire to express my thanks to Messrs. T. A. Smith and G. Rodwin who carried out this work under my direction, and with numerous helpful suggestions from Mr. J. Weinberger.

station is small (which was one reason for the choice of the station location). In consequence the percentage of complaints within 6 miles of the station is also small, a condition which would presumably exist for any station judiciously located. In order to avoid excessive numbers of complaints, it is important in the present stage of the receiver art, to avoid locating new 50-kilowatt stations within 5 or 10 miles of moderately populous communities, accustomed to powerful signals, and to keep correspondingly further away from large cities.

The highest percentage of the total complaints (28 per cent) occurs about 8 miles from the station in the zone corresponding to the 90 to 110-millivolt-per-meter field strengths. The percentage of total complaints drops to less than 10 per cent for the zone having field strengths from 10 to 30 millivolts-per-meter (about 20 to 30 miles from the station).

Beyond this zone there are practically no complaints.

The same data are presented in another form in Figure 3. Percentages *of total population* residing in localities experiencing

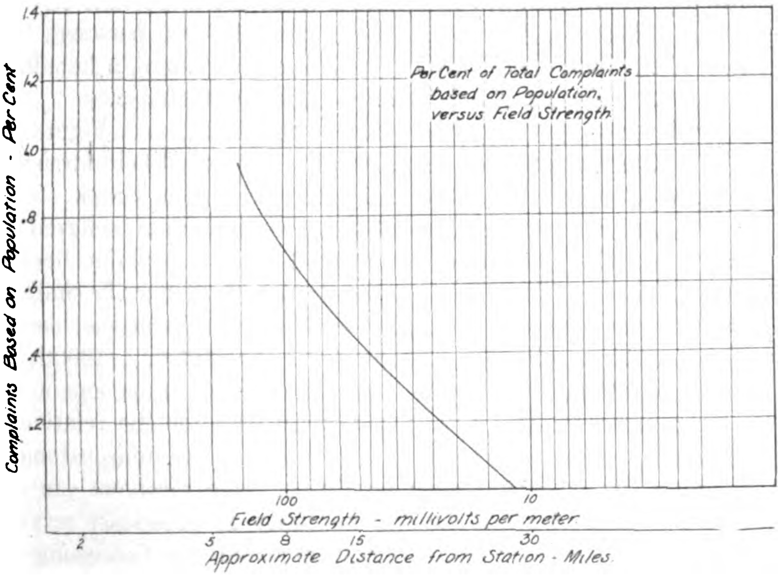

FIGURE 3

a certain field strength and complaining thereof are plotted against field strength (and corresponding distance from the Bound Brook station). The curve has necessarily been smoothed judiciously by the draftsman but is closely correct. It will be seen that for a field strength of about 170 millivolts-per-meter

(at a distance of approximately 6 miles from the station), only 1 per cent of the total population protested. At a field strength of 10 millivolts-per-meter (or a distance of 30 miles), complaints (except of the most unusual sort) disappear. These data are roughly applicable to similarly located 5-kilowatt stations by dividing distances by 3, and to 0.5-kilowatt stations by dividing distances by 10.

These figures are no doubt astonishing to those who have heard lurid reports of the overwhelming percentages of complainants, supposedly numbering hundreds of thousands of individuals. They could have been anticipated, however, by considering that the population density in the area around Bound Brook (where field strengths in excess of 60 millivolts-per-meter are produced) is about 700 persons per square mile, whereas the population density in New York City, in the neighborhood of numerous 0.5- to 5-kilowatt broadcasting stations is roughly 400 times greater or 280,000 persons per square mile. Yet there are few interference complaints from New York City listeners. Similarly there were few complaints from the important city of Newark, although its population is large (415,000 persons), because of the long experience of the Newark listeners in handling the powerful signals of a 0.5-kilowatt station in that city.

An interesting comparison can be made between Figures 4 and 5. The former gives calculated lines of equal field strength in millivolts-per-meter in the region around Bound Brook. The latter gives lines of equal percentage of complainants (referred to total population). These have been termed "isoplaint lines." The isofield and isoplaint lines are seen to be generally similar, as was to be expected. Field strengths of 20 millivolts-per-meter lead to total complaints from about 0.1 per cent or 1/1000th of total population, and may be considered to be innocuous even in the present youthful state of the art and for the relatively non-selective receivers frequently used in districts unaccustomed to strong signals. Of course highly selective receivers can do much better, and are a definite necessity as broadcast service evolves and becomes more reliable through the furnishing of adequate signals to substantially the entire listening public.

Figure 5 also shows the interesting fact that only a small portion of the area of the state of New Jersey experienced interference from the Bound Brook station. This was confirmed by the fact that 70 per cent of the New Jersey mail, even in December, 1925, and January, 1926 (at the height of the psychological (crisis, was favorable. The New Jersey listener response at

present is, as previously stated, substantially free from complaints and, in fact, highly appreciative of the excellent service rendered through summer atmospheric disturbances.

(*b*) *Dependence of Complaints on Receiver Selectivity.* In each case where demonstrations of interference reduction were given to the listener, the type of receiver experiencing the interference

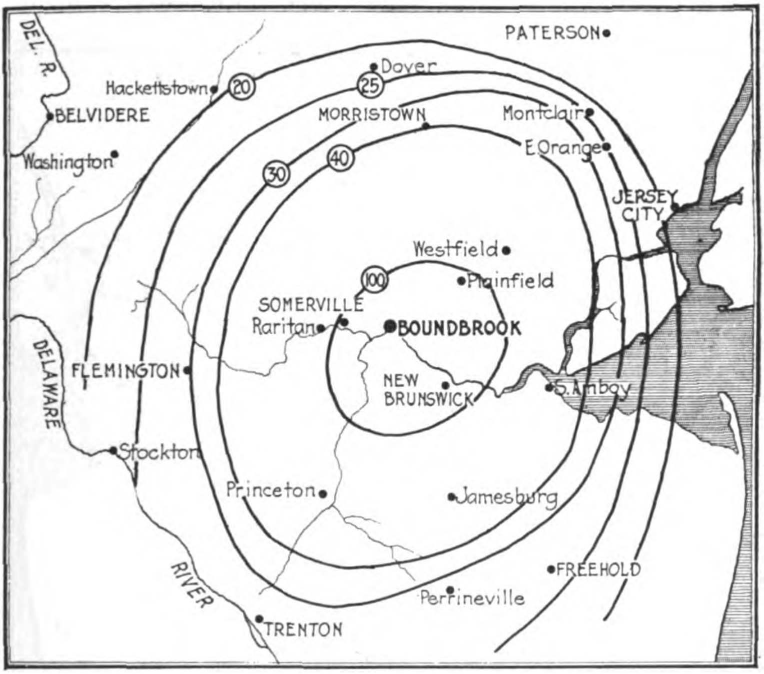

FIGURE 4—Lines of Equal Field Strength

was noted on the report blank. The percentages of each type of set found are given in Table 4.

TABLE 4

PERCENTAGES OF SETS VISITED, EXPERIENCING INTERFERENCE FROM NEARBY HIGH-POWER STATION

Single-circuit	59.0 per cent
Two-circuit	12.1 per cent
Three-circuit	27.3 per cent
Four-circuit	0.4 per cent
Super-heterodynes (including home-made)	1.2 per cent

It is seen that single-circuit receivers were most open to interference, and actually nearly 60 per cent of the instances of interference from Bound Brook were found in receivers of this type. The primary usefulness of such receivers is found in large territories where radio interference is lighter and will probably remain so.

Next came the two-circuit and three-circuit receivers. Here it was found that more than twice as many three-circuit receivers experienced interference as two-circuit receivers. However, the explanations are simple. In the first place, very few two-circuit receivers are used nowadays. In the second place, the two-circuit receivers in general utilized tuning circuits of average quality and damping. In the third place, the three-circuit re-

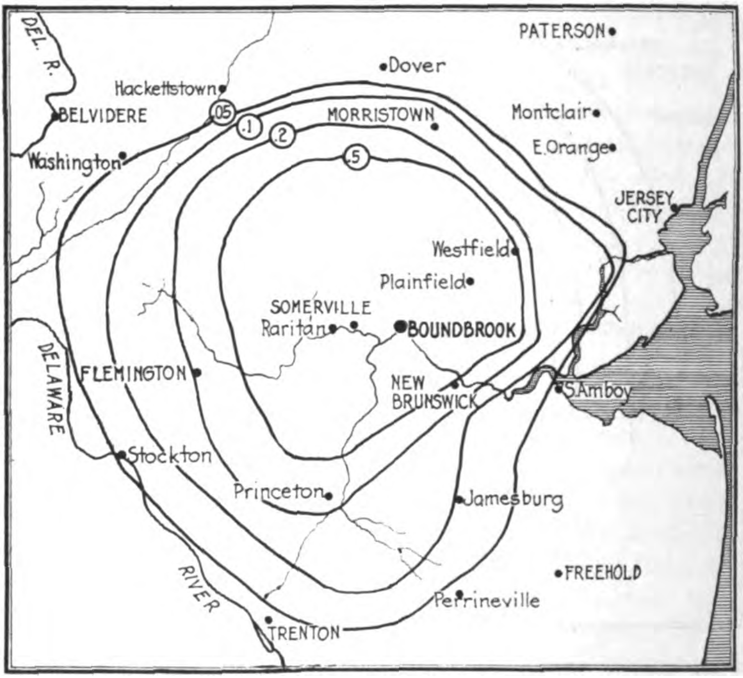

FIGURE 5—Lines of Equal Percentage of Complaints

ceivers (which were largely of the unneutralized factory-built "tuned radio-frequency" types), utilized alleged tuning circuits which were artificially damped to prevent self-oscillation. As a result, the high losses of the various circuits broadened the tuning and lowered the selectivity to the point of making such so-called three-circuit receivers quite open to interference. This is a point to be borne in mind by radio engineers interested in the progress of broadcasting.

As was to be expected, only negligible percentages of super-heterodyne receivers (including home-made super-heterodynes), and four-circuit receivers experienced interference. There was an early impression among some of the prematurely disconsolate

listeners that the interference problem presented was insuperable, and some wrote in lugubrious fashion assuring the station officials that the interference could not be eliminated by any conceivable remedy. Quite a volume of propaganda to this effect was also circulated at one time.

To study in greater detail the performance of the various types of receivers, Figures 6, 7, and 8 were prepared. These show the complaining percentages *of the total population* for various field strengths when using single-circuit, two-circuit, and

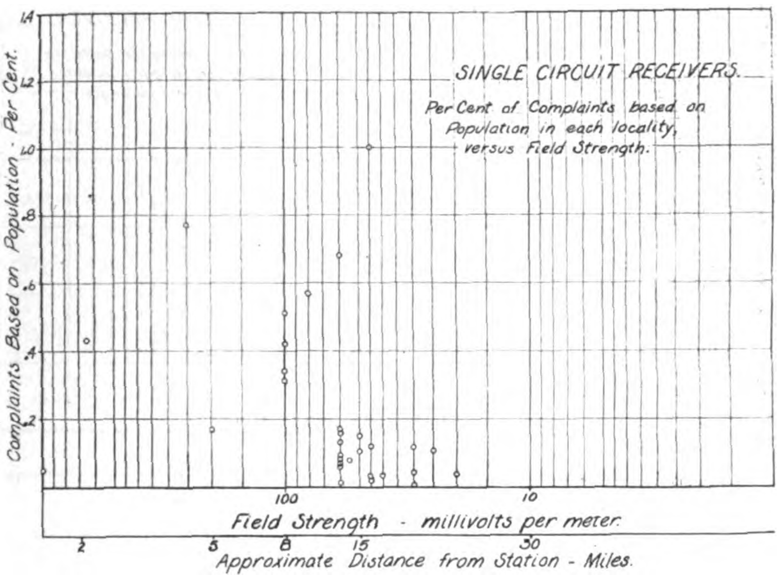

FIGURE 6

three-circuit receivers, respectively. Individual points only are shown, each corresponding to a definite town or village. The smoothed and averaged curves of Figure 9 give the same data in more useable form. As previously stated, these curves can be used with approximate correctness for similarly located 5-kilowatt stations by dividing distances by 3, and for 0.5-kilowatt stations by dividing by 10.

Again it must be remembered that what are here termed "three-circuit receivers" are widely current, but poorly selective devices. They do not include neutralized three-circuit receivers having high-quality tuning circuits, from the users of which practically no complaints were received. Clearly only superheterodyne receivers and high-grade three-circuit receivers fully

meet modern selectivity requirements in the vicinity of average modern broadcasting stations.

(c) *Dependence of Complaints on Psychological Factors.* A rather astonishing number of listeners will sign a vigorously protesting petition more or less as a favor to a friend, or for some other inherently inappropriate reason. Excessive caution leads some persons having no radio sets to protest vehemently. For example, the following were among the letters of this sort received:

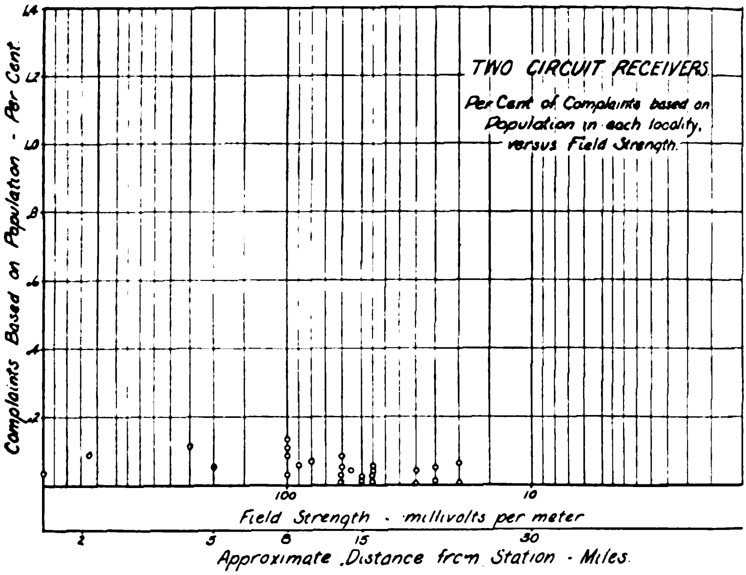

FIGURE 7

"Have no radio, but if any trouble ensues from WJZ, will come back at you for improvement."

"——— petition was signed by Mr. ———. He has no radio but he thinks perhaps some day he will have one and he wouldn't like any interference."

To our regret, we are bound to confess that we were unable to eliminate potential interference perhaps to be experienced in the distant future by prospective radio listeners using poorly selective receivers. However, there was a redeeming and bright side to the situation in the form of splendid letters of enthusiastic commendation which were received from great groups of listeners.*

*Some typical and interesting examples of these are given in my statement before the Committee on the Merchant Marine and Fisheries, House of Representatives, 69th Congress, First Session, on H. R. 5589 (Government Printing Office, Washington).

7. Clearing of Interference Complaints

A compilation of the disposition of complaints during each week has been made, covering the twenty-three weeks from December 15, 1925 to May 24, 1926. It is presented in graphical form in Figure 10. All the space shown in clear white above the shaded portions represents the percentage of listeners who were entirely satisfied after the demonstration visit. "Partly satisfied" listeners were those who agreed the interference could be eliminated, but had some adverse comment or expressed reserva-

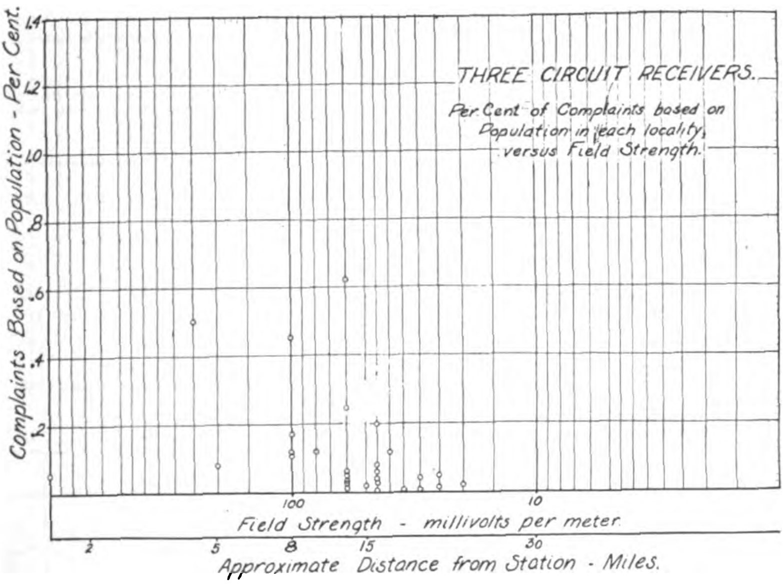

FIGURE 8

tion as to the necessity for eliminating it. Broadly speaking, such listeners felt that the responsibility for eliminable interference rested entirely or largely on the transmitting station and not at all on the receiving station. In view of the wide range of selectivity of receivers, this is an untenable and inequitable conclusion. The responsibility for the interference experienced by the user of a poorly selective receiver cannot properly rest on the transmitting station. A considerable number of listeners, increasing as time went on, cleared up their own trouble. Others, becoming convinced by their friends or local dealers that their sets were at fault, purchased new and better sets of adequate

selectivity. This group grew rapidly during the Spring of 1926, and represents a hastened radio evolutionary process.

The "irrelevant" class of complainants included some anomalous cases. For instance, there were found persons who never had owned a receiver, others who had receivers in such lamentable condition that interference made the normal signals sound no worse, and still others who, though protesting, were unwilling to accept proffered assistance. There were also a number of people who had originally complained, but who had since decided

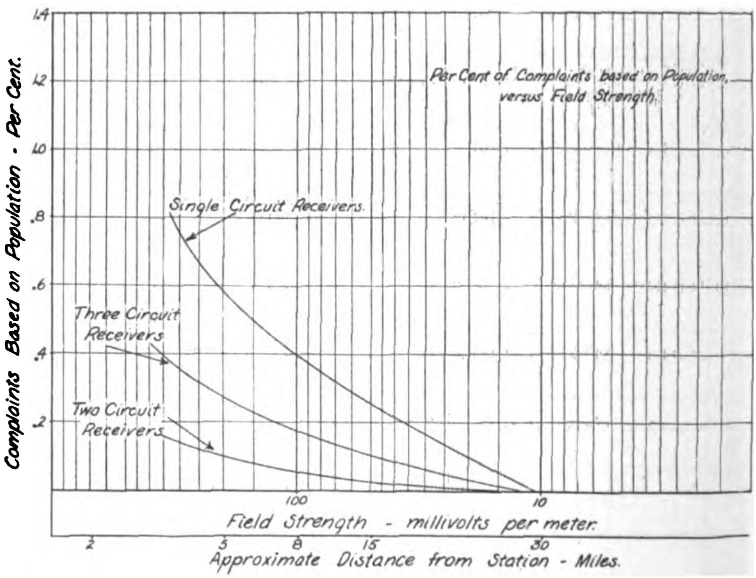

FIGURE 9

that they had no real cause for complaint. Altogether a very human situation was disclosed.

The outstanding features were the increasingly rapid elimination of the interference by the listeners themselves as time went on, and the reduction in the proportion of partly satisfied and dissatisfied complainants.

As will be seen from Table 5, the total number of complaints was less than 1,500. Only a little over 2 per cent of these remained dissatisfied, which is a most satisfactory result. It may safely be stated that these figures are far below the impressions which might have been gained from the press at the height of the initial dissatisfaction when interference from the Bound Brook station was first experienced. Sensational reports under

such conditions obviously require liberal discounts before acceptance.

The summarized disposition of the complaints is given

TABLE 5

Disposition of Complaints	Number		Percentages
Total Complaints	1473		100%
Cleared Own Trouble	97		6.6
Bought New Set	109		7.4
Partly Satisfied	83		5.6
Dissatisfied	34		2.3
Satisfied by Visit—Series Trap	706	936	63.6
Shunt Trap	100		
Both	22		
Learning to Tune	32		
Other Method	76		
Irrevelant—Have no Set	15	214	14.5
No Demonstration Desired	41		
Have no Complaint Now	86		
Out of Order or Have Sold Set	72		

graphically in Figure 11. It should be added that, during the total period covered by the preceding study, there were received

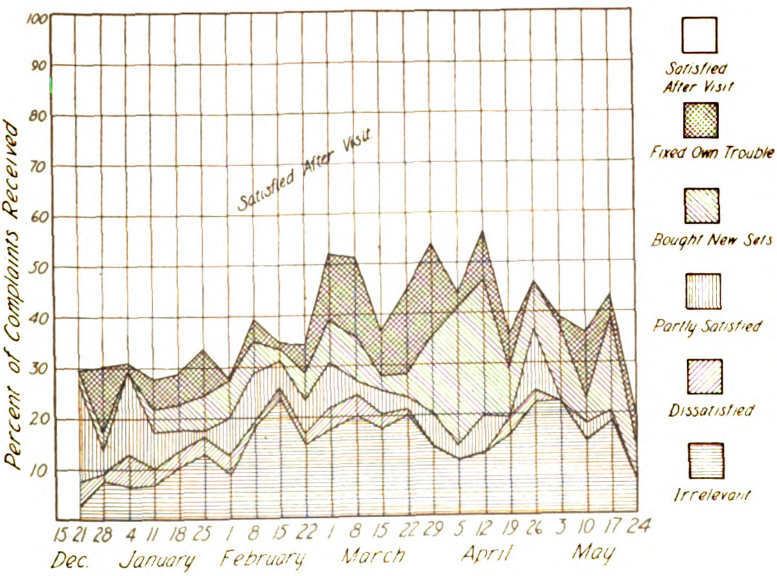

FIGURE 10

by the station approximately one hundred times as many favorable letters (from the entire United States) as complaints from the "interference area."

In other words, only a few *hundredths of one per cent* of the total listeners to the station remained dissatisfied because of interference. Certainly the proportion of dissatisfied listeners in the radio audience of a high-power broadcasting station is less than one out of every thousand, which state of affairs represents an overwhelming verdict in favor of such broadcasting and a degree

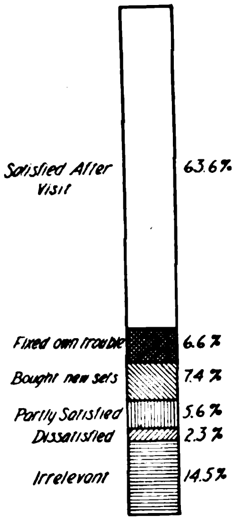

FIGURE 11

of public favor probably unattained by any other entertainment or educational enterprise.

It is not appropriate in this paper to present a study of the general comments of the listeners relative to the station nor their reactions toward the reliability of service given even at considerable distances. In summary, the listener response is exactly what would be expected from the technical considerations presented above and justifies the further development of high-power broadcasting, which, as is now clear, can safely proceed free from the imaginary bugbear of supposedly serious and unavoidable interference.

SUMMARY: The factors in station interference with broadcast reception, namely, signal field strength, receiver selectivity, and psychological reactions of the listeners, are analyzed.

Statistical data correlating these factors with interference complaints from listeners in the vicinity of the 50-kilowatt broadcasting transmitter at Bound Brook, New Jersey (WJZ), are then presented, these data being the results of a survey by a special interference reduction service.

The clearing-up of the complaints by this service, using simple methods which are described, indicates the feasibility of high-power broadcasting stations, as well as the necessity for them because of the requirement of reliable broadcasting service over large areas.

APPENDIX A

The Special Interference Reduction Service was under the general direction of Mr. Bronson S. McCutchen, assisted by Mr. C. V. Sandell, both of Plainfield, New Jersey.

The following gentlemen handled the localities mentioned:

Mr. W. J. Freuler	Bound Brook and Somerville
Messrs. W. L. Shepard and Walter G. Wright	New Brunswick
Mr. C. Brokaw	Dunellen, New Market, and vicinity
Mr. J. C. McNiece	Trenton, Princeton, Hopewell, Lambertville, Hightstown, and vicinity
Messrs. E. S. Cooke, T. L. Worth, L. Bullman, G. A. Ewald, and D. D. Porter	Plainfield and vicinity
Messrs. T. C. Rogers and R. U. S. Hillier	Westfield, Cranford, Garwood, and vicinity
Mr. R. W. Muller	Perth Amboy, South Amboy, Rahway, Metuchen, and vicinity
Messrs. Lloyd Snell and J. P. McClary	On general detail, covering remote points, outlying farms, and the like.

The above indicates the general type of geographical distribution of staff desirable in such surveys.

APPENDIX B

"People living very near to a powerful broadcasting station may find that this station comes in loudly enough to interfere with reception of other stations even when the receiving set is most carefully tuned to the station that they want to hear. Particularly is this the case in large cities like New York (which city has no less than twenty-two broadcasting stations, operating on powers up to 5,000 watts and in general with many hundreds of thousands of people living within a few miles of each of these stations). With a receiver having poor selectivity, it may be that the nearest or most powerful station will be heard no matter how the set is tuned, but with a receiver of very great selectivity,

only perhaps two or three stations of very nearly the same wave-length as the local station will be interfered with. Thus the seriousness of the interference depends upon the selectivity of the receiver, the distance from the interfering station, and the power of the latter. In the following, the methods of eliminating or greatly reducing such interference at minimum expense and trouble are given.

"Fortunately, in most cases the interference may be reduced to a point where it is unobjectionable by the use of one or more wave traps. These are simple devices that can be bought fairly cheaply, and can be made at home very easily for almost no cost beyond that of a variable condenser.

"In the great majority of cases the interference can be eliminated by the use of what is called a *series wave trap*.

"The series wave trap has two binding posts, one of which is connected to the antenna post of the receiver, and the other is connected to the antenna. (The antenna is thus disconnected from the set, and the signals have to go through the trap to reach the set. This is why it is called a series trap.) See Figure 1, which shows how to connect a series trap. In addi-

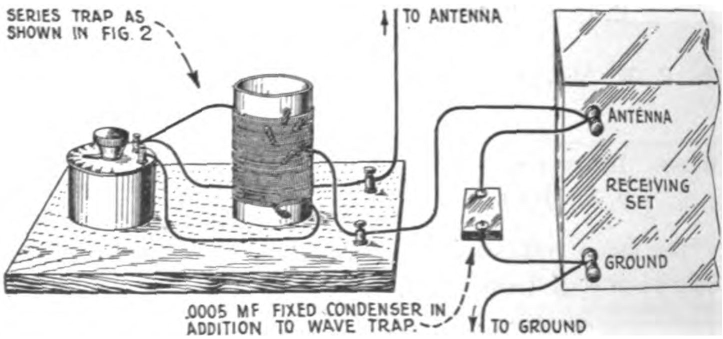

FIGURE 1

tion to the wave trap a .0005 microfarad fixed condenser should be connected across the antenna and ground binding posts of the receiving set.

"The series trap offers a very great obstruction to the interfering signal and thus reduces the amount that gets through the set, but offers comparatively little obstruction to the desired signals.

Construction of a Series Wave Trap

"A satisfactory series trap can be made of the following parts: one .0005 microfarad variable condenser, one cylindrical card-

board cover off an old dry cell (about 2½ inches in diameter), a spool of Number 24 double-cotton covered wire, a small board to mount the parts on, two binding posts or Fahnestock clips for connecting to antenna and to receiving set. (See Figure 2.) Wind a coil with the wire on the cardboard tube, with the turns close together, about 60 turns. Twist a few loops in the wire for connections at several points, say turns number 5, 10, 18, and 30, and also at the last turn.

"Remove the cotton covering from the wire on the coil at these points, so that connection can be made to any one of them by means of the flexible piece of wire marked 'A.' Such places, where connection may be made to certain turns on the coil, are called 'taps.'

"Mount the variable condenser and coil on a wooden board, provided with two binding posts as shown in Figure 2. Connect

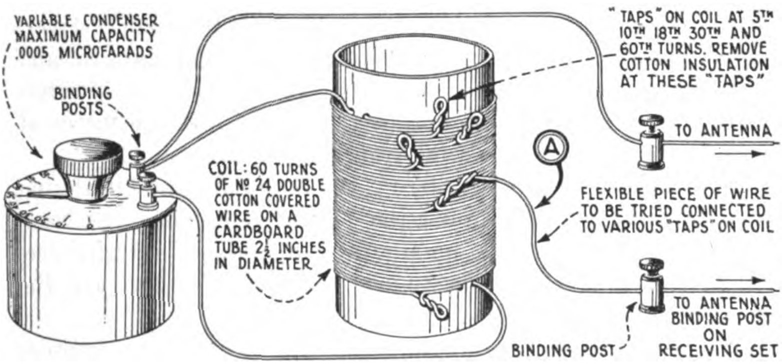

FIGURE 2

the first and last turns of the coil to the variable condenser, as shown in the figure. Then connect one of the binding posts on the board to one of the binding posts on the variable condenser, as shown in the figure. To the other binding post connect a piece of flexible wire (the No. 24 cotton covered wire can be used, but a piece of stranded flexible, insulated wire would be better) and remove the insulation from the free end so that it may be connected to one of the 'taps' which were made on the coil, as will be described in the second paragraph below.

OPERATION

"Remove the antenna wire from the 'antenna' binding post on your receiving set and connect it to the right-hand binding post on the wave trap, and connect the left-hand binding post

on the wave trap to the binding post on your receiver to which the antenna wire previously went (see the figure). Next, connect the .0005 microfarad fixed condenser between the antenna and ground binding posts of the receiving set.

"Now twist the 'flexible' wire connection on the wave trap, around the 'tap' at the 30th turn, being sure to make a good connection. Then start up the receiving set, set the wave trap condenser pointer at zero, and tune for some desired station. This may come in at a different place on the receiver dials from those found previously. If the interfering station is now heard along with the desired one, turn the knob of the wave trap condenser very slowly until the interference disappears.

"If the desired station goes out along with the interfering one, change the flexible connection on the wave trap to the 18th turn, and repeat the operation. If the same thing still occurs, try 10 turns and 5 turns in succession. In each case, before changing the tap connection, try re-tuning or re-adjusting your receiver, to see whether or not the desired station can be brought in, and also re-adjusting the wave trap slightly to keep out the interfering signal. A certain amount of back and forth adjustment between the receiver and wave trap may be necessary.

"If with the tap connection on the 30th turn the interfering signal can still be heard under the desired one, when the wave trap is tuned, to give its maximum reduction of interference, change the tap connection to the 60th turn and repeat the operation described above.

"A certain amount of experimenting will be necessary, in order to learn the effect of the wave trap on the receiver adjustments, and in order to learn how to adjust the wave trap as well as what tap on the coil is best for your particular receiving set and antenna.

"If the trap does not work when first made and connected, inspect it carefully to see that it was made in accordance with the foregoing instructions. Traps such as the one described have actually been made, and have been used successfully with many hundreds of receivers, of the widest variety of manufacture.

Loop Sets

"Less interference will be found usually when using loop sets because the loop is more selective than an antenna. Also the loop can be turned into a position where the interference is very much reduced. And finally, a wave trap can easily be made that will cause a great decrease in interference, as follows:

"Wind about 20 turns of double-cotton-covered Number 24 wire in a bunch around a regular size 45-volt 'B' battery (which is about 7 inches by 8 inches). Slip the coil off and tie or tape it together to keep from falling apart. Connect it to a variable condenser. Then hold the coil near the loop and adjust condenser to make the interference as little as possible."

APPENDIX C

Radio Corporation of America

Special Interference Reduction Service

(The following to be filled in by the Radio Corporation of America Representatives)

A receiving set located at New Brunswick ....
(Town) (County) (State)

and belonging to Mr L P Janeway 192 Livingston Ave
(Name of owner or listener)

has experienced interference from W J Z .... at Bound Brook N. J.
(Station call letters) (Town, State)

The type of Receiver is ...., 5 Tube neutrodyne ....
(Name of maker) (Model or Type Number)

Successful Method of Eliminating Interference Series trap ....
(Series trap, shunt trap, series and shunt

....
traps, link circuit, shorter antenna, rotating set, or other methods to be mentioned)

Date of call of RCA representative April ......, 8 ....
(Month) (Day)

Name of RCA representative Walter L. Shepard ....

....

In order to get the opinion of a large number of set owners as to the success of the interference elimination methods demonstrated to them under field conditions, it will be greatly appreciated if the following report will be filled in.

An attempt was made to eliminate interference at my home from the above station, and the results of the demonstration were successful in eliminating the trouble. Thanking you for the assistance

....

....

....

....

(Signed) L P Janeway

COMBINED ELECTROMAGNETIC AND ELECTROSTATIC COUPLING AND SOME USES OF THE COMBINATION

By

EDWARD H. LOFTIN AND S. YOUNG WHITE

The energy transfer characteristic of the normal forms of coupling employed in radio receivers is well known to all of us and in the usual forms transfers energy more readily at higher frequency than lower. This characteristic makes for higher efficiency and consequently greater tendency towards instability of commercial vacuum tube receivers on the high-frequency portion of the broadcast band.

Our investigations of the combination of electromagnetic and electrostatic couplings were for the purpose of removing this objectionable characteristic, and we undertake in this paper to outline some of the more salient of our observations during these investigations, as well as some uses made of the combination. One of these features is the use of a coupling means which has its frequency characteristic reversed in that its most efficient energy transfer takes place at the lowest frequency. By suitably combining this coupling means with a coupling having the usual characteristic, we are enabled to so design the combined coupling that the total energy transfer will vary in any desired manner with frequency.

Starting in an elementary way, let us consider the various voltages existing in the oscillatory circuit shown in Figure 1. With an impressed voltage E_I across both the inductive leg and the capacitive leg, any desired fraction of this voltage may be obtained by tapping the inductive leg, resulting in a voltage E_L, which increases in value with the number of turns in the tapped portion of the inductance. Similarly the capacity leg may be tapped by dividing its capacity into two series portions, as is shown by condensers C_1 and C_2. Assuming a resonant condition, the voltage developed across C_2 will be inversely proportional to its ratio with C_1. For example, if C_1 and C_2 are equal, then the voltage E_{C2} will be just half the impressed voltage E_I.

*Received by the Editor June 8, 1926. Presented at a meeting of the INSTITUTE OF RADIO ENGINEERS, New York, N. Y., June 30, 1925.

If C_2 is larger than C_1 it will have proportionally less voltage across it, and vice versa.

Keeping these voltage relations in mind, let us examine Figure 2. In this circuit C_1 has been made variable, while C_2 remains fixed. It is evident that C_1 has now become the variable tuning condenser for the system. However, in varying C_1 we find that we continuously vary its ratio with C_2. The larger C_1 becomes in its relation to C_2, the higher will be the voltage E_{C2}. However, when C_1 is maximum, the frequency to which the system is resonant is minimum, and we have the condition that

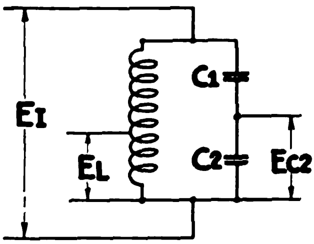

FIGURE 1

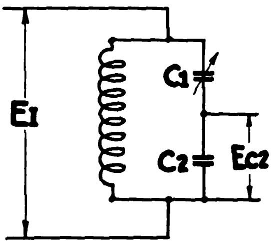

FIGURE 2

the voltage E_{C2} is maximum when the frequency is minimum, and this voltage can be made any desired portion of E_1 by adjusting the capacity ratio of C_2 and C_1.

This point might be brought out a little more clearly by a specific example. Assuming the condenser C_1 is a variable with a minimum capacity of 50 $\mu.\mu.$f., and a maximum of 500 $\mu.\mu.$f., and that C_2 is a fixed value of 5,000 $\mu.\mu.$f., let us examine the voltage developed across C_2. At the maximum frequency C_1 will be at its minimum value—50 $\mu.\mu.$f. C_2 is now 100 times as large and will have roughly 1 percent of the voltage E_1 across it. At the lowest frequency C_1 will be 500 $\mu.\mu.$f., and the value of C_2, remaining at 5,000 $\mu.\mu.$f., will now be ten times as large as C_1, and voltage E_{C2} will be roughly 10 percent of E_I.

One practical application of this effect is shown in Figure 3, where the arrangement of Figure 2 is used as a portion of an interstage coupling for a three-electrode vacuum tube amplifier system of the so-called tuned radio frequency type. The principal addition lies in the use of a coil $L1$, through which the output of the tube passes before reaching the branch point of the two condensers $C1$-$C2$. The energy transfer due to $L1$ has the normal characteristic of increasing with an increase of frequency, while the coupling due to the varying reactance of $C2$ with variations of tuning condenser $C1$ has the reverse characteristic.

It is obvious that the electromagnetic coupling, due to $L1$ may be combined with the electrostatic coupling due to $C2$ in either an opposing or an aiding phase. If they are combined in an opposing phase and are of approximately equal coupling effects, it is found that at the minimum frequency, the electrostatic coupling will predominate, while at maximum frequency the electromagnetic coupling will predominate. Thus there will be some point in the frequency band where they will be equal, and since they oppose, a balance will obtain at this point and no energy transfer will take place. It is, therefore, obvious that

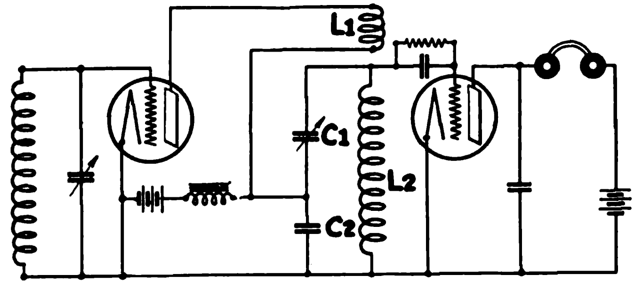

FIGURE 3

an adjustment of this kind would be of no value in receivers which must operate equally well throughout a wide range of frequencies.

To satisfy the requirements of receivers that must cover wide ranges of frequencies, such as broadcast receivers covering the broadcast band, we have found that by combining electromagnetic and electrostatic couplings to transfer energy in phase, and using at the same time the reverse characteristics of these two couplings properly adjusted, most satisfactory results are obtained in the production of a total energy transfer, which will, if desired and by proper adjustment, increase with frequency increase, decrease with frequency increase, or remain substantially constant throughout the frequency band. Figure 4 is illustrative of the manner in which the variable characteristic of electromagnetic coupling is combined with the reverse frequency characteristic of the variable electrostatic coupling, the figure showing how we obtain an overall energy transfer which can be made substantially constant throughout a wide range of frequencies (f). In Figure 4, the curve $L1$ represents the variation of energy (w) transfer with the electromagnetic coupling and the curve $C2$ a predetermined variation of energy transfer with the electrostatic coupling, and the dotted line represents

the in-phase combination of the two. The portion below *f* represents a reverse phase effect of *C*2.

Again considering Figure 3, we find that by judicious proportioning of constants we can so adjust the coupling that at any point throughout the frequency range there is the correct amount of inductive reactance in the plate circuit to maintain the tube in a condition of critical regeneration. The tube can also be made to oscillate or to regenerate slightly throughout the band, as desired. It will be noted that the plate circuit is energized through a radio frequency choke. Any actual design

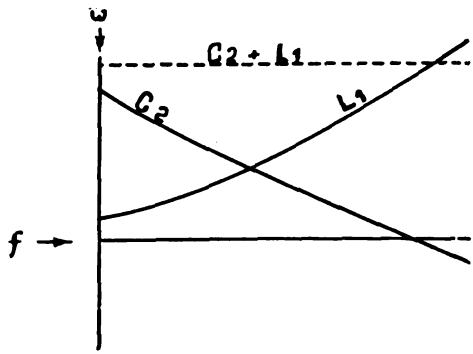

FIGURE 4

of this type of receiver must take into consideration the amount and phasing of stray feedbacks, if operation with extreme regeneration is required. The frequency band covered by this combination is quite large, larger than usual, due to extreme loose coupling at the highest frequencies.

A commercial application of the coupling is shown in Figure 5, and it will be noted that the system is similar to that described in Figure 3, with the exception of condenser *C*3.

The principal cause of oscillation in a radio frequency amplifier system is feedback through the capacity between electrodes of the tube. It is necessary that this feedback energy be in phase with the impressed grid voltage in order to produce regeneration and oscillation. It has been found that this positive feedback occurs only when the plate circuit is predominantly inductively reactive. If the plate circuit reactance is predominantly capacitive, energy will also be fed back through the tube capacity, but in a negative phase. However, if the inductive and capacitive reactances of the plate circuit are equal, they create a non-reactive condition leaving only a resistive plate circuit, which will not feed back through the tube capacity in either sense.

When this non-reactive condition exists, the plate circuit becomes quite independent of the tube characteristics, since no feedback can occur through the tube capacity. In actual practice, commercial models are designed for this condition so that tubes of any type or make can be used with no tendency toward regeneration or oscillation.

In Figure 5 the condenser $C3$ is in series with the plate to provide the required capacity reactance to balance the inductive reactance due to the coupling means. Since the capacity of $C3$ is fixed, its reactance varies inversely with the frequency, so it

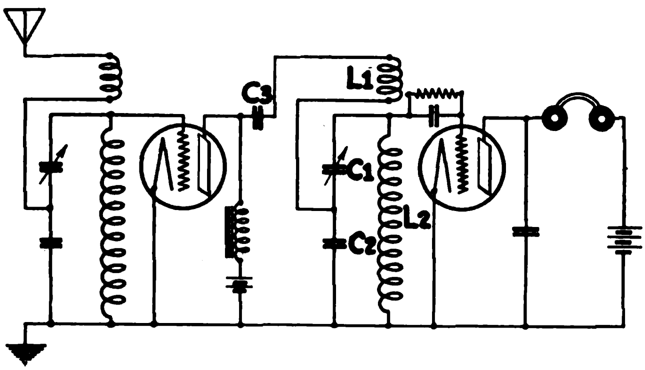

FIGURE 5

is necessary to design the coupling to provide an inductive reaction which also varies inversely as the frequency, and to the same degree. This is accomplished by properly proportioning the couplings and values of C_1, C_2, C_3, L_1, and L_2. In actual practice, it is occasionally found desirable to leave the plate circuit with slight predominance of capacitive reactance, since under these conditions a slight negative feedback will exist in the tube, which will oppose any stray positive interstage feedbacks. In other words, the relative values of C_1, C_2, C_3, L_1 and L_2, vary in different styles of assemblies.

In Figure 5 the automatic variation of the antenna coupling is also employed. This allows the coupling at the highest frequency to be quite loose, which is found to widen the frequency band covered by the tuned circuit associated with the antenna. The so-called absorption hump, which occurs when the antenna tune falls in the reception band, is also much reduced in effect.

A variation of the circuit is shown in Figure 6, where it is used to couple the plate circuit of a regenerative detector directly to the grid circuit, to produce either regeneration or oscillation

throughout the band. If a coupling similar to that previously discussed is used, it is found that the instantaneous polarity of the fed-back energy is in a negative sense, which necessitates the re-arrangement shown, which allows direct capacitative feed-back in a positive phase. The variable resistance R controls the amount of feedback. This form of coupling is also used between stages of a radio-frequency amplifier, where it is necessary to ground the condenser $C1$, for single control receivers and the like.

The phenomena so far discussed allow designing circuits which will permit a vacuum tube amplifier or detector type of

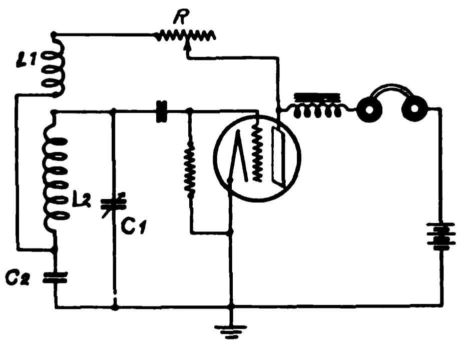

FIGURE 6

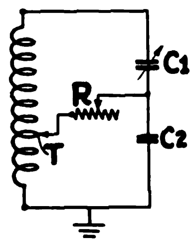

FIGURE 7

receiving set to oscillate at the upper or lower or at all dial settings. Figure 7 shows an arrangement which allows oscillation at any one intermediate dial setting.

As we have observed before, the point between the two capacities $C1$, $C2$ is at a potential difference to the grounded side of the system, which is determined by the ratio of $C1$ to $C2$. Whatever value this voltage has we can also always find a point T on the inductance of exactly the same potential to ground. If we join these points with a resistance R of any value, no current will flow through R, since both points are at equal potential to ground. If we now vary $C1$ as in tuning, we find that a potential difference develops across R, since point T remains at substantially the same voltage, while the potential across $C2$ varies. This potential difference becomes greater as we vary $C1$ either up or down from the value at which we balanced the system. If we balance midway of the dial reading of $C1$, we find that to be the only spot where the absorbing action of R has no effect, and if this Figure 7 arrangement is placed across the input of a vacuum tube whose plate circuit is sufficiently reactive to allow

of oscillation throughout the frequency band, R can be so adjusted as to stop oscillation at all points except the balance point. If we balance at the lowest frequency, the damping action of R will increase with the frequency, and can be adjusted to prevent oscillation throughout the band. Precaution should be taken that R does not reach a sufficiently low value to allow the portion of the inductance below T to form a resonant circuit with C_2.

While we have investigated and used numerous other applications of the above, those we have outlined are considered sufficient to illustrate the principles involved.

SOME MEASUREMENTS OF SHORT WAVE TRANSMISSION*

By

R. A. Heising† and J. C. Schelleng† and G. C. Southworth‡

Introduction

The advent of short waves in the communication field has brought to light certain peculiarities of radio transmission previously unknown. The distances over which short-wave communication has been possible, together with the vagaries reported from time to time, raised the question, at one time, as to whether the phenomena involved were in any wise orderly or entirely chaotic. Much progress has since been made in the process of systematization until now it appears that there is really more order to the behavior of short waves than was previously suspected. One of the outstanding pieces of work in this direction is that of Dr. A. H. Taylor[1], who has correlated the work of amateurs, much of which has been reported in Q S T, with the short wave experience of the Navy. This has shown that in general short waves tend to skip the surface of the earth for a portion of their journey and be received at a distance with considerable intensity. The magnitude of this skip distance seems to vary with the time of day and the frequency (wavelength) used. Theories and calculations have been offered which for the present, at least, satisfactorily explain many of the short wave abnormalities.[2] It is the purpose of this paper to present transmission data on field strength, fading and telephonic intelligibility, together with some of their variations with time and distance. The studies of which these data form a part are still incomplete, and do not include a sufficient range of conditions

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[1]A. H. Taylor, Proc. I. R. E. Dec., 1925, p. 677.

[2]Larmor, Phil. Mag., 1924.

Nichols and Schelleng, Bell System Tech. Jl., Vol. IV, 1925, p. 215; Popular Radio, Oct., 1925.

Taylor and Hulburt, Phys. Rev., Feb., 1926, p. 189.

Rice and Baker, Paper presented at midwinter convention A. I. E. E., N. Y. C., February, 1926.

to be altogether conclusive. Therefore, many deductions possible at this time have been deferred to a later date when the attending facts have been more definitely established.

Scope

In the study of transmission the plan generally pursued was to send observers with the necessary measuring apparatus to points of vantage. Test signals were sent out hourly on each of several frequencies in accordance with a prearranged schedule. In most cases the schedule extended over several consecutive days. The tests were arranged to provide specific information on the diurnal variation of electric field strength, intelligibility and noise for each frequency, and for each distance where observations were made. The observing points were in some cases so selected as to bring out any marked differences that might exist between over-water and over-land wave propagation, and in others were arranged in a straight line to reduce the number of possible variables. Simultaneous measurements were made at as many as six locations. The observations totaled over 6,000 where each observation consisted of an average field strength measurement, a maximum field strength measurement, noise measurement, intelligibility measurement and fading observation.

The frequency range covered was from 2.7 to 18 megacycles, roughly 111 to 16½ meters. This was covered in seven convenient steps with occasional tests on other frequencies. The greater part of the observations were made on 2.7, 4.5, 6.8, and 9.7 megacycles. Most of the tests were made between September and December, 1925. They include observations in several directions up to over 1,000 miles, and a few in England.

Experimental Apparatus

The transmissions were made largely from the short wave laboratory at Deal, N. J. The transmitter is of the oscillator-amplifier type, in which the frequency is set by an oscillator, and harmonics are generated and amplified. The oscillator was stabilized against frequency variations. The carrier was modulated at a level of about 200 watts after which it was amplified by water-cooled tubes and delivered to the antenna. The radiated power varied with frequency, being about 1 kw. on 9.7 megacycles (31 m.), and 4 kw. on 2.7 megacycles (111 m.). In addition to the regular Deal transmitter, a similar low-power transmitter was operated at the building at 24 Walker Street, New York City, during two regular tests. This extended the

range to 18 megacycles (16½ m.). The radiated power did not exceed 200 watts.

Various types of antennas were used at Deal. The one usually employed on the lower frequencies consisted of a vertical conductor functioning approximately as a quarter-wave radiator. For the higher frequencies a vertical copper rod was used, which operated substantially as a half-wave radiator. Figure 1 is an

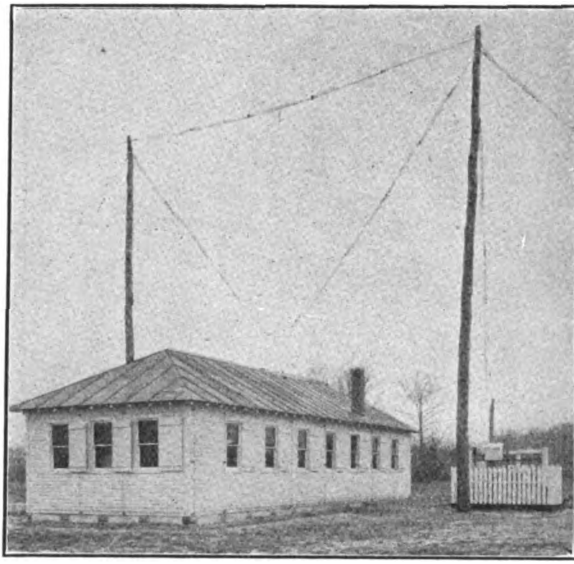

FIGURE 1—Short Wave Transmitting Laboratory and 66-meter Antenna at Deal, N. J.

illustration of the building and one of the antennas used at Deal. At the Walker Street transmitter half-wave radiators were used in all cases.

The observations were taken with field strength measuring sets and automatic field strength recorders of types which will be described in another paper. Illustrations are given in Figures 2 and 3. Loops were used when possible on all measuring and recording sets, but vertical antennas were resorted to whenever the signal became too weak for the loop.

Diurnal Transmission Curves

Sample field-strength curves are given in Figures 4 to 7, inclusive, for 24-hour periods for Nantucket, Detroit, Mich., Columbus, Ga., and a complete trip on board a ship en-

route from New York to Bermuda. The diurnal curves vary from day to day, but in the main have certain characteristics which repeat. Where our tests ran several days, we averaged the readings for each hour of the several days to secure an average diurnal curve for each observing point. Such curves are shown in Figures

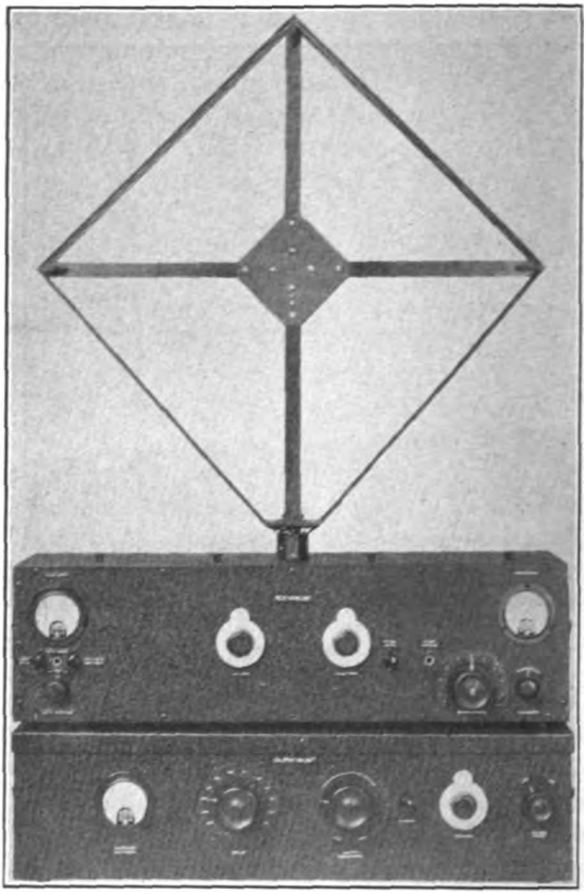

FIGURE 2—Portable Short Wave Field Strength Measuring Set

8, 9, and 10 for England, September 10-13, Columbus, Georgia, and Fairfax, Virginia, December 11-14, inclusive. As a rule, on the lower frequencies, a minimum field strength occurs during the day. On 6.8 megacycles (44 m), at about 200 miles, the minimum usually occurs at night. On still higher frequencies

at 700 miles there appears to be a minimum both during the day and during the night.

The curves for 4.5 megacycles taken in England, Figure 8, show an absence of signal during the day, but a fairly strong signal at night. This curve should not, however, be taken as an example of what can be expected at that distance every time, as other experiments showed that at the time of these particular

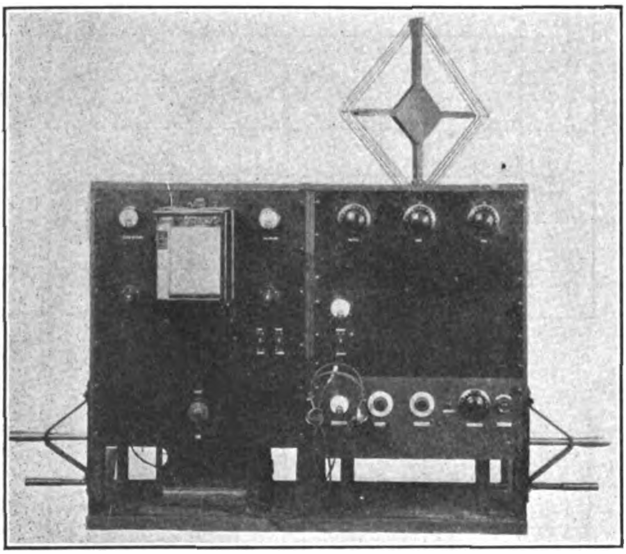

FIGURE 3—Automatic Recording Set. This Apparatus Makes Continuous Records of Either Signal or Noise Field Strength

tests the transmission to England at this frequency was exceptionally good.

VARIATION OF FIELD WITH DISTANCE

Until short waves attracted attention about three years ago, it was thought that their attenuation as a function of distance was always very much greater than for the longer waves. For distances up to 100 miles this is found to be true. However, the phenomenal distances reached by short waves with small power have shown that our theory of transmission was incomplete. In order to explain how such distances are covered it has been assumed that at least a portion of the wave travels in an indirect overhead path, being deflected back to earth by some upper ionized layer and suffering little attenuation over this longer path.

Our observations bear this out. Up to a distance of about 100 miles the attenuation was of the order of magnitude expected, after which the signal, instead of decreasing with distance, actually increased. Figure 11 shows curves taken at two wavelengths over water up to a distance of 30 miles, where both transmitter and receiver were located at the water's edge with no intervening land. The distance was too small to secure any

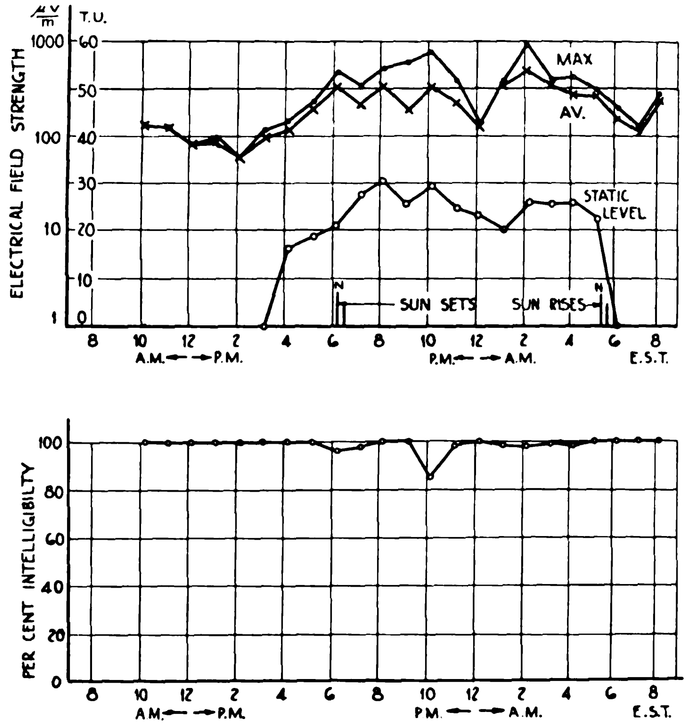

Figure 4—Typical Curves of Field Strength, Noise and Intelligibility Taken at Nantucket, Mass., Sept. 11-12, 1925, 2.7 mc.

exact measurements of attenuation, though the results indicate that excessive attenuation does not occur. Incidentally, there was not the slightest indication of fading or bad quality in these tests. With over-land transmission made at the same time, the attenuation was observed to be enormous, due evidently to obstructions on the surface of the ground and to the ground itself. The observations plotted in Figure 11 were not made simultaneously at the various locations, but were made in succession. Some were checked at other times, indicating that at such small distances the time of day had little or no effect.

Figures 12 and 13 show measurements made over distances up to 1,050 miles on 6.8 megacycles (44 m.). The curves give average field strength as measured simultaneously at three stations in a straight line, one group of readings being 7:00 p. m., and the other at midnight on four successive nights. These figures show that the transmission curve, as a function of distance

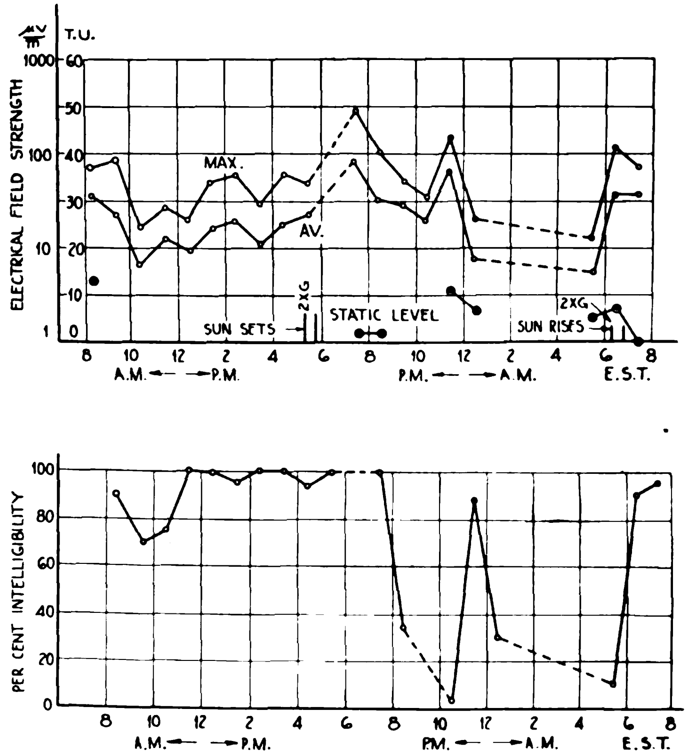

FIGURE 5—Typical Curves of Field Strength, Noise and Intelligibility Taken at Detroit, Mich., Oct. 21-22, 1925, 6.7 mc.

varies from time to time and in some cases varies over a wide range.

To secure a curve as a function of distance which could be called an average curve, the measurements taken at each observation point were averaged. That is, a mean daylight value was obtained for each location by averaging all the readings taken when the path of the wave lay entirely in a daylight region. A night average was obtained in a similar way. Several days' data at each location were made use of. Figures 14, 15, and 16 represent average curves as a function of distance on 6.8, 4.5 and

2.7 megacycles (44, 66 and 111 m.). Figure 14 indicates that the overhead wave on 6.8 megacycles (44 m.) comes back to earth, giving a maximum signal about 600 miles away at night or 350 miles in the day. At these points the signal strengths are of the order of magnitude that are normally received over 50

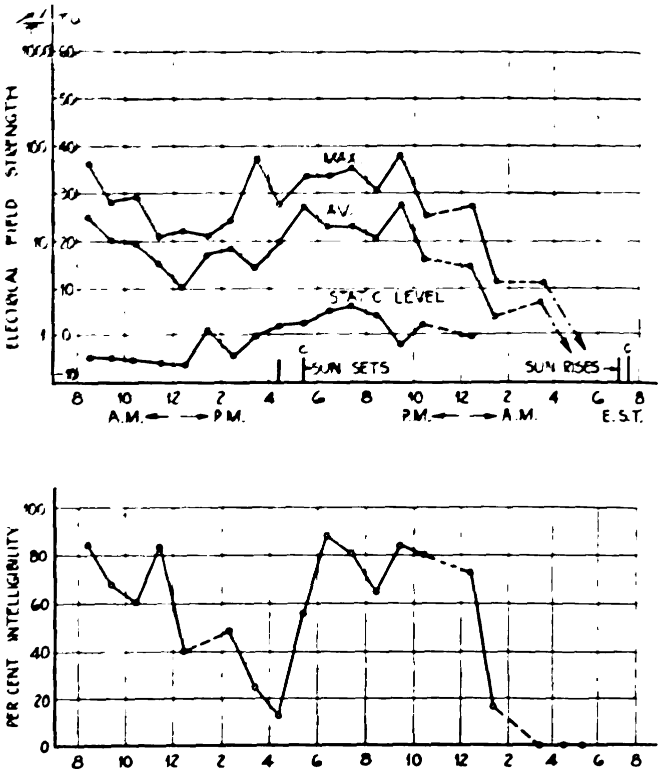

FIGURE 6—Typical Curves of Field Strength, Noise and Intelligibility Taken at Columbus, Ga., Dec. 14-15, 1925, 9.7 mc.

miles of water. Even at a thousand miles the signal is as strong as it is over 75 miles of water. There is a region of low field strength a short distance from the transmitter which is at present interpreted as a region which is too close to the transmitter to receive much by the indirect wave and a little too far to receive much of the direct wave. This appears as a decided depression in the curve. This region of weak signals becomes much more pronounced at shorter waves and gives rise to what is called the skip distance. This skip distance hollow increases in width as well as depth as the frequency is raised. Figure 15 shows the

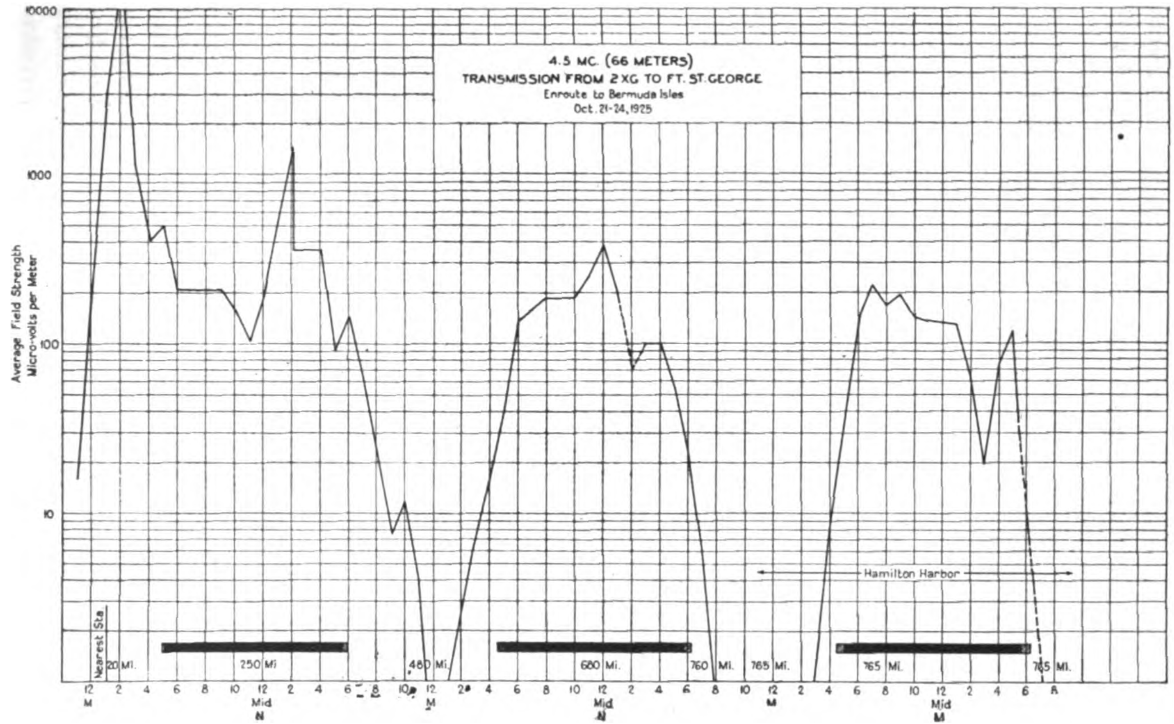

FIGURE 7—Field Strength Received From Deal, N. J., Aboard a Boat Enroute New York to Bermuda, Oct. 21-24, 1925, 4.5 mc.

curves of field strength and intelligibility as a function of distance on 4.5 megacycles (66 m.). The skip distance effect is also quite noticeable here. The distance at which the maximum signal occurs is reduced to around 300 miles at night and 250 in the daytime. The skip distance depression is sharper and narrower than for 6.8 megacycles (44 m.), though it must be stated that the shape of this is partly guess-work, being based upon measurements taken at 30, 90 and 240 miles. Figure 16 gives

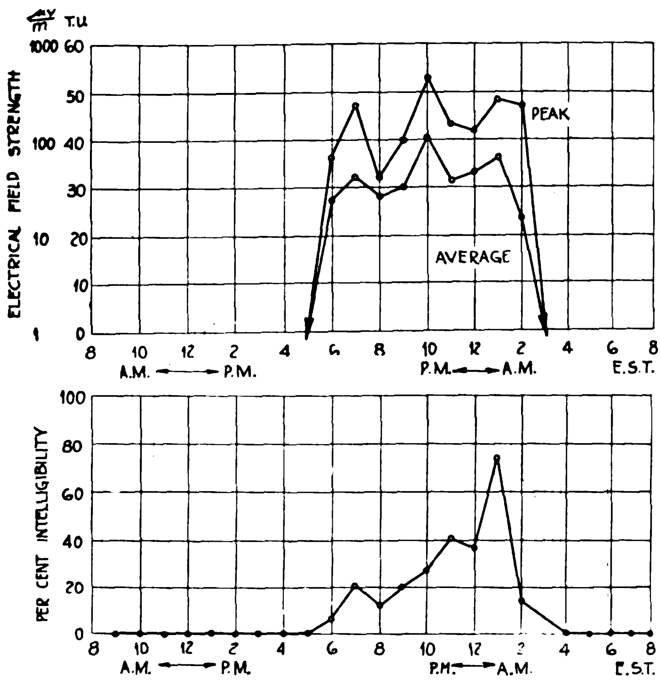

FIGURE 8—Curves of Average Field Strength and Intelligibility Received at Chedzoy, Somerset, England, from Deal, N. J., Sept. 10-13, 1925, 4.5 mc.

corresponding curves for 2.7 megacycles (111 m.). At this wavelength there is just an inkling of the skip effect. The magnitude of the signal at distances above 200 miles is, however, considerably greater than what would have been secured if there were actually no overhead wave. In the region where the signal is secured from the ground wave only, the strength is very much less at all of these three wavelengths than that given by the Austin-Cohen empirical formula. Beyond the skip distance the signal is usually actually greater.

Figure 8, for transatlantic transmission at 4.5 megacycles, is of interest, because of the fact that the field strength at times reaches values as great as ten times that calculated by assuming the inverse distance law. It is well to remember, however, that since the wave is presumably diverging in two dimensions rather

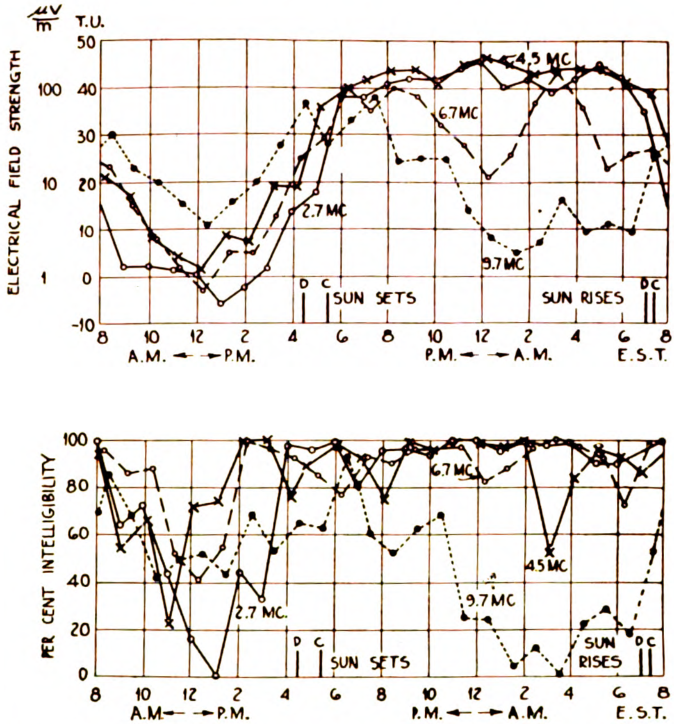

FIGURE 9—Diurnal Curves of Average Field Strength and Intelligibility Secured at Columbus, Ga., Dec. 11-16, 1925, on 2.7, 4.5, 6.7 and 9.7 mc. Times of Sunset and Sunrise are Indicated by D=Deal, C=Columbus

than three, we should not expect the inverse distance law to apply.

IDEALIZED TRANSMISSION SURFACES

As indicated above, field strength is a function of both distance from the transmitter and the hour of the day. Therefore, a complete graphical representation for one frequency requires a three-dimensional figure such as shown in Figure 17. A figure of this kind may be considered as a surface made up from an infinite number of diurnal variation curves, each taken at a different distance from the transmitter. Since measurements

taken at a given point are subject to wide variations, it has been necessary to idealize the data to a considerable extent, taking into consideration only those characteristics which are known in general to repeat day after day. A plane passed through each figure at the 1 microvolt-per-meter level has been taken arbitrarily as the limit or noise level below which a signal is no longer useful. If a higher level had been chosen, it would not have

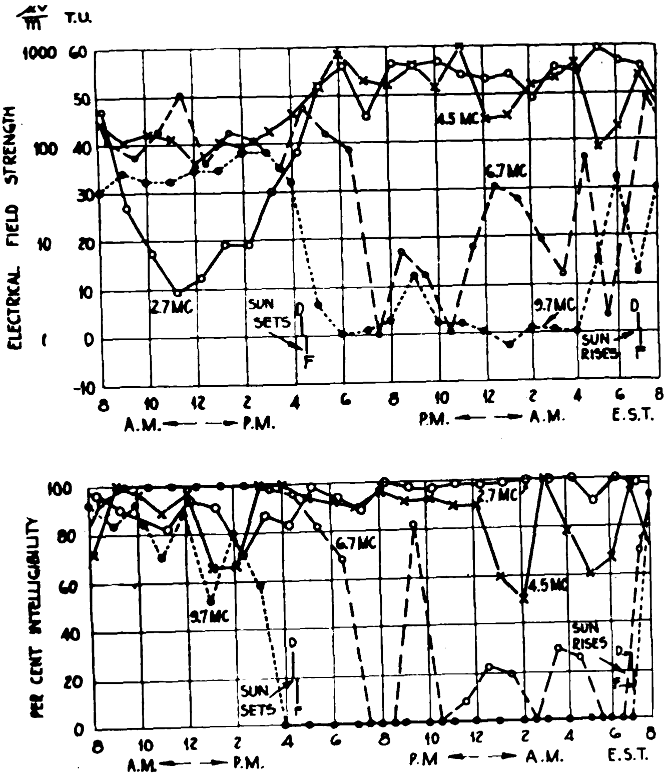

FIGURE 10—Diurnal Curves of Average Field Strength and Intelligibility Secured at Fairfax, Va., Dec. 11-16, 1925 on 2.7, 4.5, 6.7 and 9.7 mc. Times of Sunset and Sunrise are Indicated by D=Deal, F=Fairfax

seriously altered the shape of the figures. Actually the datum level adopted was approximately the lower limit of the measuring methods used. In constructing these surfaces the general procedure was to smooth out each data curve and correct it to approximately 1 kw. of radiated power and piece the whole into a general mean which seemed to be most representative of average conditions.

It should be borne in mind that data taken at a given place vary considerably from day to day. On this account, the surfaces as well as the average curves shown represent only the outstanding characteristics to be expected, and this picture of trans-

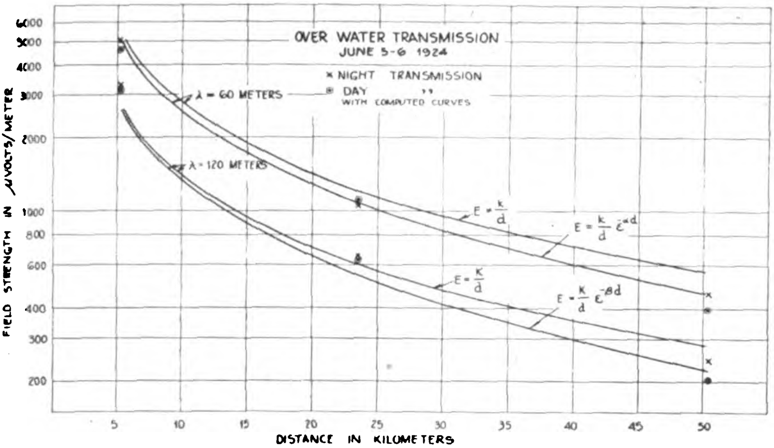

FIGURE 11—Field Strength Measurements for Transmission Entirely Over Sea Water at Frequencies of 2.5 and 5 mc., Distances up to 50 km. Within the Range of these Curves the Austin-Cohen Values Agree with Those Calculated According to the Method of Sommerfeld

mitting conditions for any given frequency holds only in a general way for that region of the radio-frequency spectrum speci-

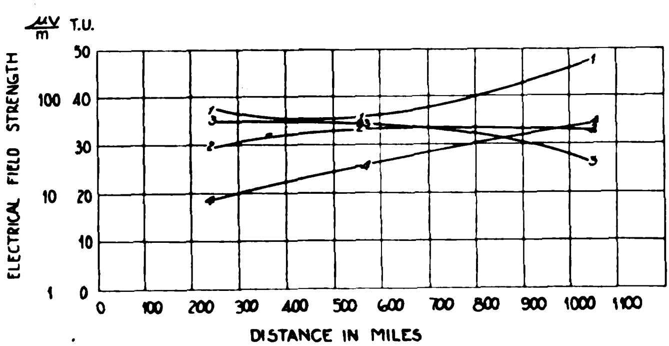

FIGURE 12—Average Field Strength as a Function of Distance on Four Successive Days at 7 p. m. for 6.7 mc.

fied. It does not distinguish between east and west and north and south transmission. On some days 6.7 megacycles (45 m.) data resemble closely those depicted for 4.5 megacycles (66 m.), while on the other days they may be more like the 9.1 mega-

cycles (33 m.) surfaces shown. Consequently, it is rather difficult to specify at just what wavelength and at what distance discontinuities, such as the night minimum shown in the third surface begin. Cosmic phenomena, such as observed about April 15 of this year, seem to alter materially the whole aspect of short wave transmission as it also does transmission at 5,000 meters. It is convenient to regard these surfaces as means of widely varying instantaneous states, which are changing even while observations are being taken. From this point of view fading is the direct result of the rapid transition from one state to another.

Discussion of Transmission Surfaces

As indicated above, a typical diurnal variation curve for 2.7 megacycles (111 m.), is in general a periodic curve having a

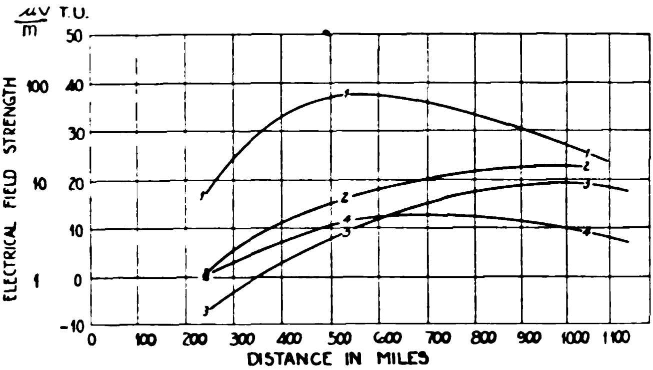

Figure 13—Average Field Strength as a Function of Distance on Four Successive Days at Midnight for 6.7 mc.

maximum at night and a minimum in daylight. For points near the transmitter, the difference between day and night signals is less than at a distance and at no time does the signal sink below the arbitrary datum level of 1 microvolt per meter. At more remote points, say 500 miles, the signal is heard only during the night. The number of hours for good signals becomes less and less the greater the distance. Observations made in England indicate that the 2.7 megacycles (111 m.) signals are rarely heard when moderate amounts of power are used. This means that the top of the surface seldom appears above the assumed noise level. However, when the signal does appear, it usually takes place about midnight. The distance of 300 miles is of particular interest in that beyond this point signals would not ordinarily be heard throughout all the 24 hours. This distance probably

varies considerably from day to day, depending on influences not yet known.

The transmission surface for 4.5 megacycles (66 m.) resemble closely that for 2.7 megacycles (111 m.). However, on closer

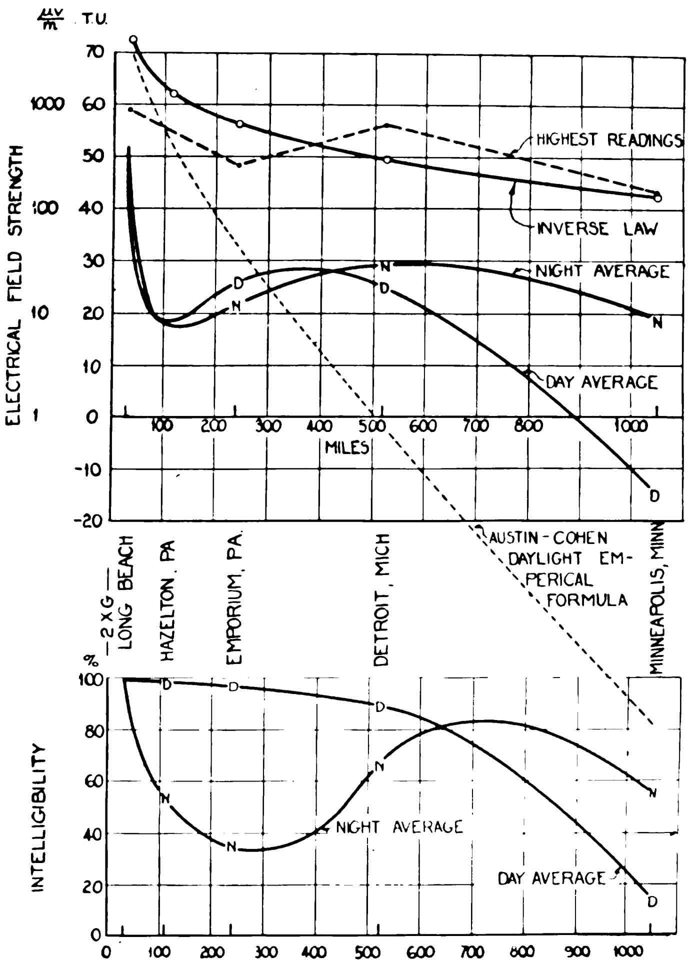

FIGURE 14—Field Strength and Intelligibility as a Function of Distance for 6.7 mc. Curves Represent the Average of Data for Several Days

examination it will be observed that the maximum night signals are somewhat stronger, and that, in general, these signals may be heard during more hours of each day. The night depression observed for this surface is much more pronounced than in the

preceding surface. In some instances depressions have been observed in the diurnal variation curve around midnight even at distances of several hundred miles. In a few cases this has been observed in the 2.7 megacycles (111 m.) surface.

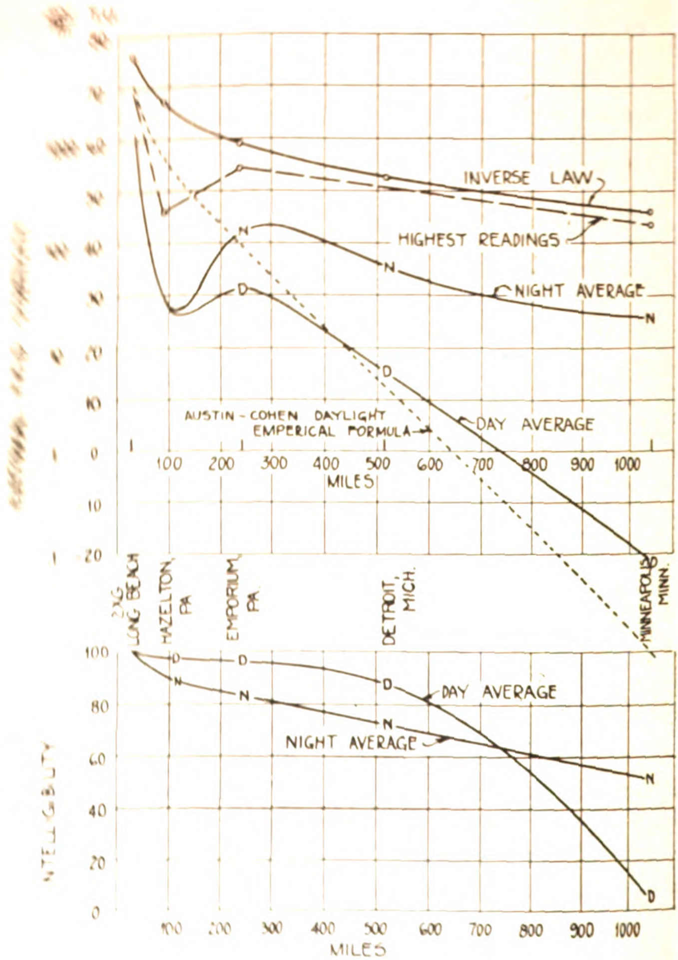

Figure 15—Average Field Strength and Intelligibility as a Function of Distance for 15 m.—Average for Several Days

The distance at which faintest signals can just be heard becomes considerably greater as the wavelength is reduced. One would infer from this that for a given amount of radiated power the shorter wavelengths would in all cases be more efficient. This is not true as we have already shown.

The 6.7 megacycles (45 m.) surface differs markedly from that for the longer waves. The slight depression observed in the 4.5 megacycles (66 m.) surface at 200 miles and after midnight has now developed into a pronounced bifurcation extending beyond the limits of the figure. The lowest point is probably

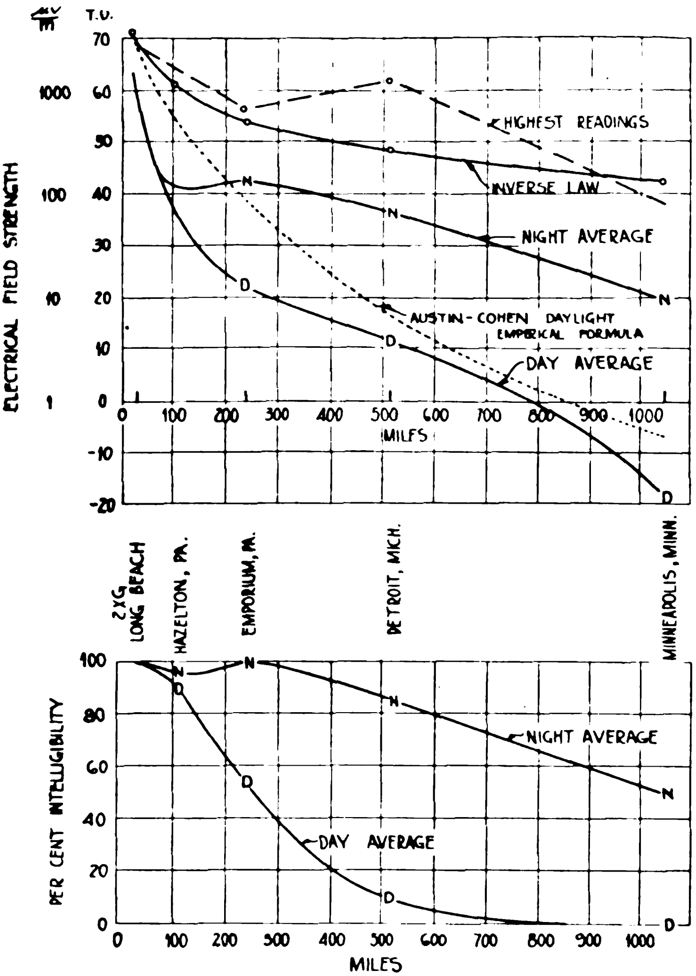

FIGURE 16—Average Field Strength and Intelligibility as a Function of Distance for 2.7 mc. Average for Several Days

about 300 miles from the transmitter and, of course, is below the zero level. The maximum distance for noon signals has been pushed out to perhaps about 700 miles. The width of this weak signal period appears to vary somewhat from night to night. At one time tests were made on 5.7 megacycles (52 m.) to find out

whether the transmission on this frequency resembled the 4.5 megacycles (66 m.) transmission more than that for 6.7 megacycles (45 m.). On this particular day the night opening in the

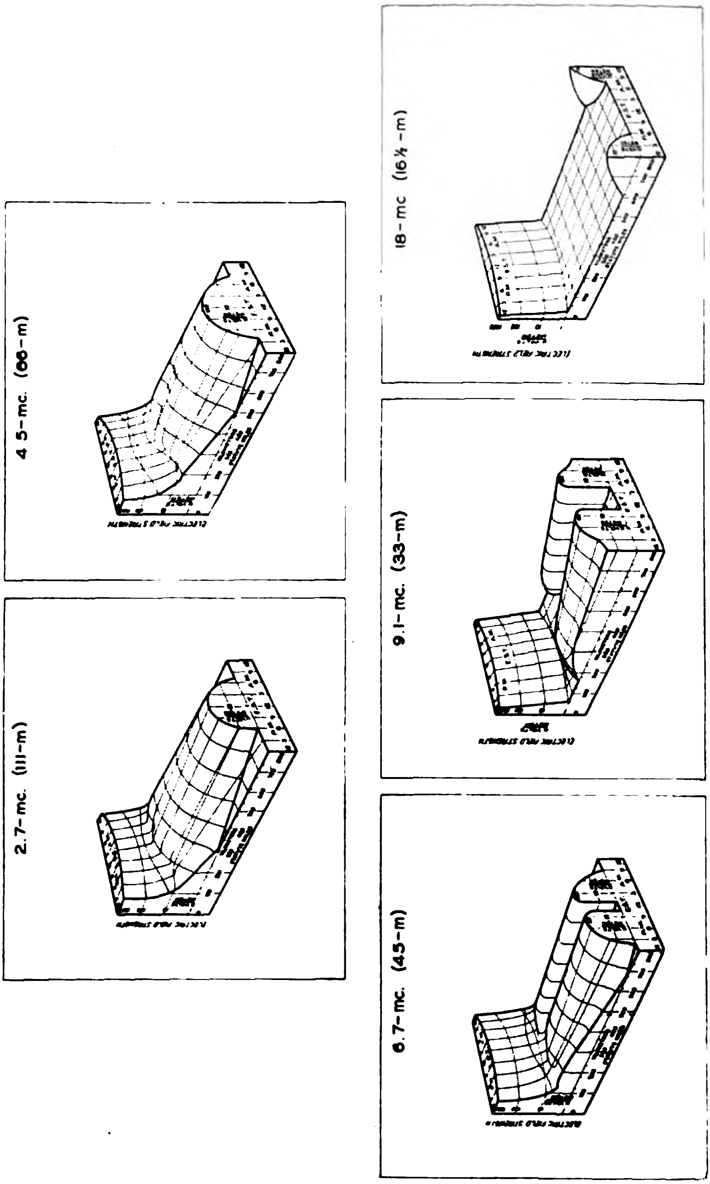

FIGURE 17—Idealized Transmission Surfaces, Variation of Field Strength with Time and Distance

6.7 megacycles surface was unusually wide. A very definite but narrower one was observed at 5.7 megacycles, and the night signals at 4.5 megacycles were found to be very unstable.

In passing from the 6.7 megacycles surface to that for 9.1 megacycles (33 m.), one observes that the depressions mentioned above have become so pronounced that a short skip distance results where no signal is heard at any hour of the day, and the night opening is considerably widened. It is well to bear in mind that while, for practical purposes this skip distance is very real, it is only the result of the surface intersection evident at the longer wavelengths, taking place below the arbitrary zero level chosen. With improved receiving methods, this distance may be reduced somewhat. It will be observed that the maximum distance for noon signals has increased until it has passed on out beyond the 800-mile point. However, there are signs of the noon diminution of signals remaining. As indicated by the surface, signals are heard at all hours of the day at points near the transmitting station.

The last surface in the figure shows what may be expected on the very high frequency of 18 megacycles (16 m.). It will be noted that the skip distance has been increased considerably and the time when signals may be heard has been reduced to a very few daylight hours. The time limits when signals were heard are known more definitely than the distance which the surface extends along the distance axis.

Considering the several surfaces consecutively in the order of increasing wavelength or decreasing frequency, we observe a general continuity from one type to another. As we pass from 18 megacycles (16½ m.) to 9.1 megacycles (33 m.), the daylight signal, evident only at distances of approximately 750 miles, increases in magnitude and covers a greater portion of the time and space domain. At 9.1 megacycles (33 m.) the signal becomes somewhat weaker about noon, but the surface continues to cover more and more of space and time. After the frequency has been decreased to 6.7 megacycles (45 m.), this area has extended back to the transmitter and covers practically all but a few of the night hours. During this time a noon signal depression has developed, so that at 800 miles there are two times each day when the signal is weak. Upon further decrease of frequency the night signal depression closes up and the maximum distance for noon signal reception recedes toward the transmitter as the whole surface sinks downward toward the arbitrary noise level of 1 microvolt per meter.

Intelligibility

In determining the usefulness of short waves it was felt that

signal strength was by no means the only observation [illegible]. Rapid fading, though not interfering with field strength measurement, is frequently present. It was found to play havoc with speech quality at times. It was therefore decided to make tests on the intelligibility of received speech in addition to the field strength measurements.

In these tests a series of [illegible] words was transmitted and the percentage of words clearly understood at the receiving station was taken as a measure of the intelligibility. It is realized that such an intelligibility test is by no means exact, in fact different observers listening under the same conditions get material differences. On the other hand, considering the large number of observations required and the widely varying conditions under which they must be made, it is necessary to use as simple an intelligibility test as can be devised. These percentages, although not an exact measure of intelligibility, undoubtedly give us an idea of telephonic limitations.

In order to insure that the intelligibility measurements were really observations of the effect of the transmitting medium on the radiated wave, all known precautions were taken to eliminate distorting effects dependent upon the apparatus. The frequency of the master oscillator was stabilized. High quality microphones, amplifiers and modulating coils were used. Monitoring observations were made to insure good quality in the amplifying and modulating processes. Receiving apparatus was located, whenever possible, away from all wires, lines, or other obstructions that would distort the field or introduce noise. The observations were usually made at the same audio level.

The intelligibilities thus measured were plotted along with other data. Sample daily curves are included in Figures 4, 5, and 6, and average daily curves in Figures 8, 9, and 10.

At each location all of the daylight and night values were separately averaged. Curves of average intelligibility have been plotted along with the curves for field strength in Figures 14, 15, and 16. To a certain extent the intelligibility is dependent upon the signal strength. This is especially the case with the apparatus used when the signal strength falls below 10 microvolts per meter, due to the fact that at these low intensities the necessary amplification brings in sufficient noise to impair the intelligibility. On the other hand, as is readily seen from the curves for 6.7 megacycles (45 m.), poor intelligibility is often observed at field strengths which, under other circumstances, are accompanied by high intelligibility. Under the conditions

of these tests rapid fading has been found to be the greatest element in reducing the intelligibility on short waves.

On 6.7 megacycles, in the region of the skip distance depression, the day average stays up, while at night it drops, due to the greater fading, although the signal strengths are closely the same in the two cases. The fading on 4.5 megacycles is less than on 6.7 megacycles, and the night intelligibilities (Figure 15) are correspondingly higher. At both these frequencies the weakness of signal began to affect the intelligibility at 1,000 miles. On 2.7 megacycles at 500 miles and over, the low day intelligibility is due to the total absence of signal during a large part of the day.

Over-land vs. Over-water Transmission

On several occasions strong signals of the order of 1,000 microvolts per meter have been observed at Long Beach, Long Island, which showed an extremely rapid falling off in intensity as the receiving station was moved inland in a direction away from the transmitter. The distance from Deal to Long Beach is about 31 miles, of which about 3 miles is over land. At a point 12 miles inland from Long Beach the signal strength had decreased from 1,000 down to around 100. As indicated in Figure 11, entirely over-water transmission should not produce such a rapid falling off. This is corroborated by the observations shown in Figures 14, 15, and 16, for the 90-mile point where the path was mainly over water. It was suspected that, although signals received nearby were attenuated rapidly over land, there would be very little difference between over-water and over-land transmission to great distances if the signals travelled by an overhead path.

Last December, therefore, tests were made for the purpose of comparing over-land vs. over-water transmission. Some of the data are plotted in Figures 18 and 19. The curves in Figure 18 are for over-water and over-land stations, which are a little over 200 miles from Deal. The average field strength curves by day and by night, for these places are similar both in shape and in value. They are closer than would be expected from any previous experimental results. In Figure 19 similar curves are given for distances slightly over 700 miles. They show even less dissimilarity in magnitude than the ones taken around 200 miles. The signals received at Bermuda and Columbus, Georgia, were most likely entirely of the overhead type, while the 2.7 megacycles (111 m.) wave at Nantucket probably contained some ground wave.

[illegible] for the 200-mile [illegible] the 700-mile distances [illegible] the latter. It is evident [illegible] experiments, that for distances [illegible] miles and less than a thousand miles there

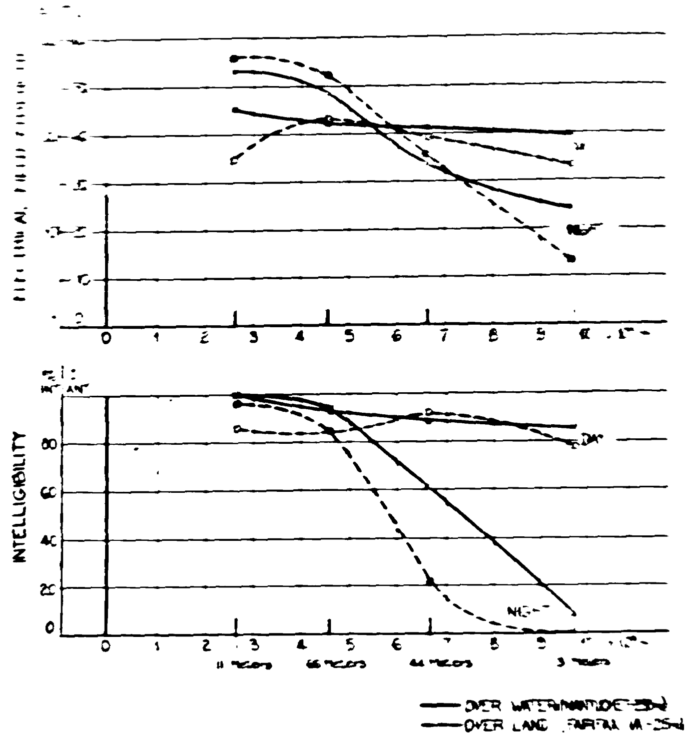

FIGURE 18—Comparison of Over-land and Over-water Transmission. Field Strength and Intelligibility Are Shown as Functions of Frequency for Distances of Approximately 200 miles

is very little difference between over-water and over-land transmission.

Transmission as a Function of Frequency

Figures 20 and 21 give the average strength of the signals received at Quogue, 90 miles, and Detroit, 500 miles, as a function of frequency. The difference between day and night signals at Quogue is very small. The signal strength decreases as the frequency is raised. There are many reasons for believing that the Quogue signals were largely of the ground wave type. The curves in Figures 18 and 19, referred to in connection with

over-land vs. over-water transmission, are plotted also as a function of frequency. At distances of 200 miles there is no great variation in value of the day signal with frequency. The night signals appear to show a falling-off at the higher frequencies, the signals being actually weaker during the night than during the day. At the greater distances, such as at Bermuda and Columbus, the day signal increases with frequency. In this particular case,

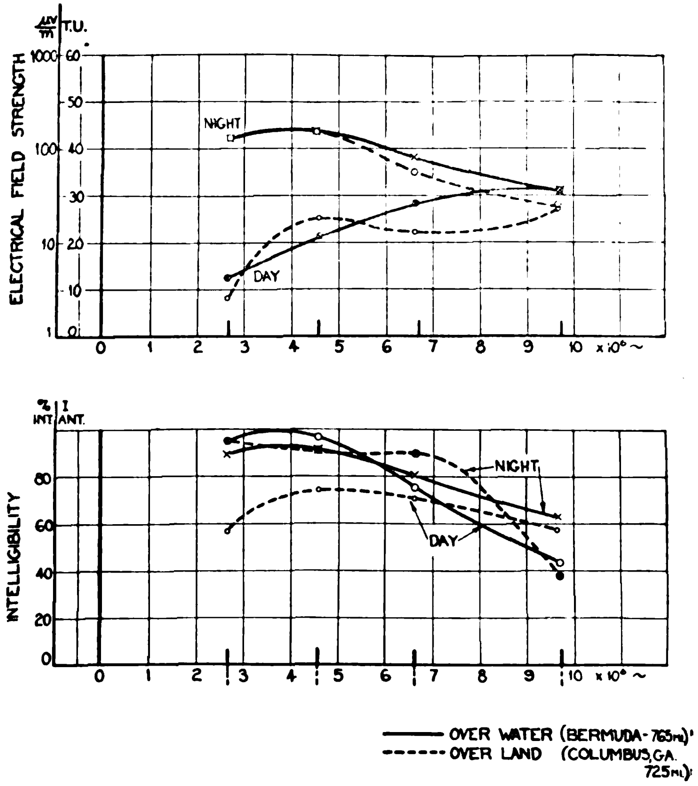

FIGURE 19—Comparison of Over-land and Over-water Transmission. Field Strength and Intelligibility are Shown of Frequency for Distances of Approximately 700 miles

the day signals reach the same value as the night signals at about 10 megacycles (30 m.). At Detroit, slightly over 500 miles, Figure 21, the same characteristics appear as at Bermuda and Columbus, but the day and night signals in this case would be of equal value at a point just above 7.5 megacycles (40 m.).

NIGHT AND DAY EFFECTS

Inspection of Figures 18, 19 and 21, shows that at some frequency the curves for signal strength at night will cross those

for the daytime and that the value at which they cross is connected with the distance. Inspection of the diurnal curves shows that in some locations on some frequencies the day signal is stronger than the night signal. This is contrary to experience at lower frequencies, where better transmission is obtained at

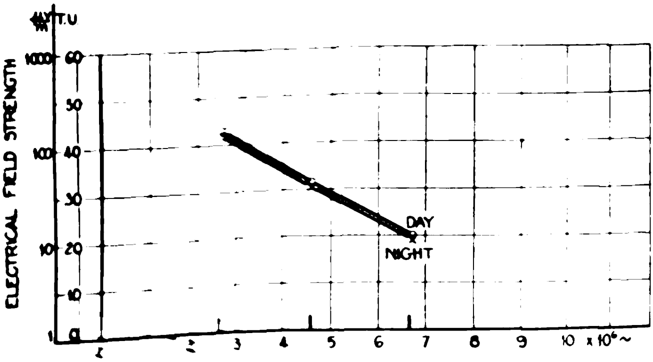

Figure ... Strength as a Function of Frequency at a Point Where ... Wave Dominates. Signals Received at Quogue at ... All Over Sea Water Except for About Two Miles Near Deal

night ... the day. The relation between average night and ... shown in Figure 22, where the difference between ... transmission in transmission units is plotted ... frequency. The curves are labelled according

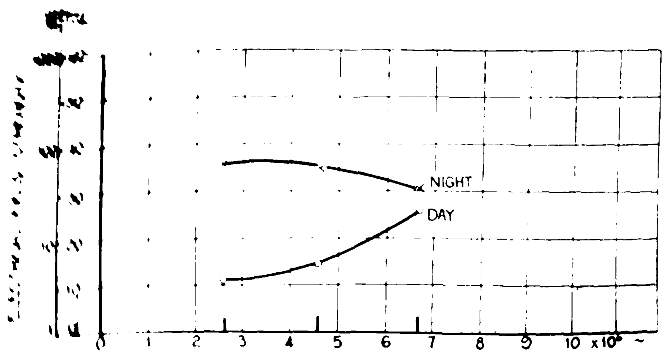

Figure 21—Signal Strength as a Function of Frequency at a Point When the Ground Wave Does Not Dominate. Signals Received at Detroit, 520 Miles Over Land

to the location at which the data were secured. They show that around 2.7 megacycles (111 m.), the night transmission is universally better, but as we go to the higher frequencies it becomes less and less so, until finally, in the case of Nantucket,

Emporium, Pennsylvania, and Fairfax, Virginia, all located approximately 220 miles from the transmitting station, a change occurs, and from 6.7 megacycles (45 m.) to the higher frequencies the day transmission is better. At other locations still further away, there are indications that for each distance a frequency will also be found which will give better signals by day than by night. This checks with the present theory of short wave trans-

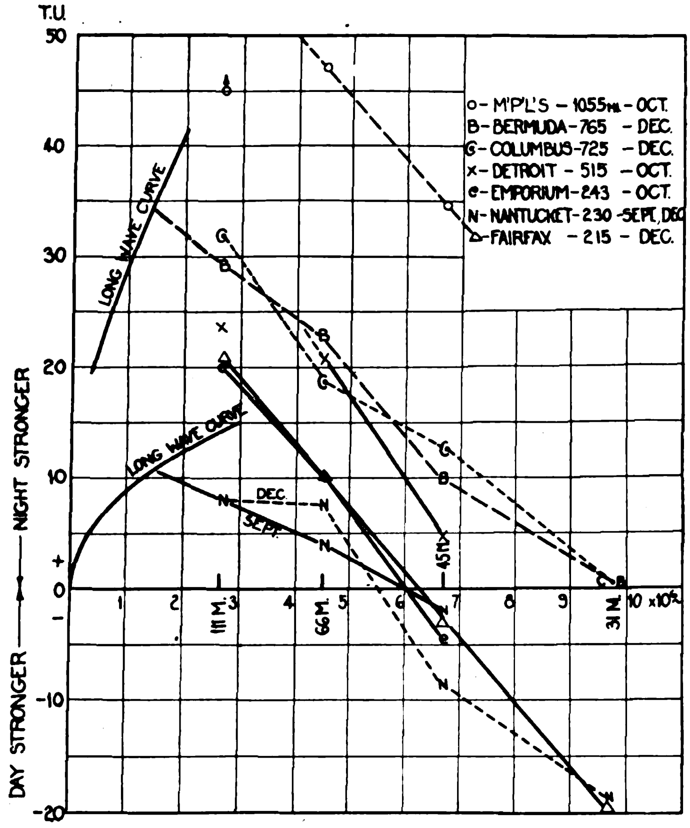

FIGURE 22—Ratio of Average Night to Average Day Signals as a Function of Frequency

mission in that the overhead wave returns to earth at greater and greater distances as the frequency is increased.

On this same sheet are plotted two semi-empirical long wave curves for distances corresponding to Nantucket and Bermuda. The values for day transmission were assumed as those given by the Austin-Cohen formula. The values for night transmission were assumed as being inverse law values without any

absorption. This second assumption makes the ordinates of the curve larger than their actual values should be. The two over-water curves, which were secured at Bermuda and Nantucket, when extrapolated backwards, intersect these curves in the neighborhood of 1.5 megacycles (200 m.). The maximum advantage of night over day transmission should occur around this value and the change in sign of the slope in passing the intersecting point would indicate that some unusual phenomena occur there. It may be more than a coincidence that this point is near the critical frequency, which Nichols and Schelleng pointed out as due to the motion of free electrons in the earth's magnetic field.

Fading and Quality

All rates of fading have been observed from zero to probably 100 per second. Records were taken, both with an oscillograph and with signal strength recorders. Most fading is relatively slow; also, it is more prevalent at night. At any given location frequencies very close together do not fade simultaneously. The types of fading may be the same, but there is no connection between their maximum or minimum values. Figures 23 and 24 are copies of our fading records, made with the recorder at Columbus, Georgia, and Hamilton, Bermuda, between 4:05 p. m. and 8:45 p. m., December 15, 1925. Comparison of these records shows that at times the types of fading at the two locations are the same and at other times they are different. A survey of all our records at locations for which we have simultaneous observations, shows that there is a slight tendency towards similar types of fading occurring at two locations. As a rule the fading on the longer waves is less than on the shorter, although there are cases where the fading on the shorter waves is small.

The observed fading might be classed as first, uniform or synchronous (where carrier and side band fade together), and second, asynchronous (where the frequencies do not fade together). The former is easily compensated for by a gain control adjustment while the latter is not. Asynchronous* fading is most troublesome at the moment the carrier is reduced to the magnitude of the side bands or lower. When the carrier drops to such a value, the distortion of the signal becomes so great that a word may be lost. When in addition, fading is rapid, that is,

*This type of fading is discussed by Bown, Martin and Potter in the I. R. E. Proceedings for February, 1926.

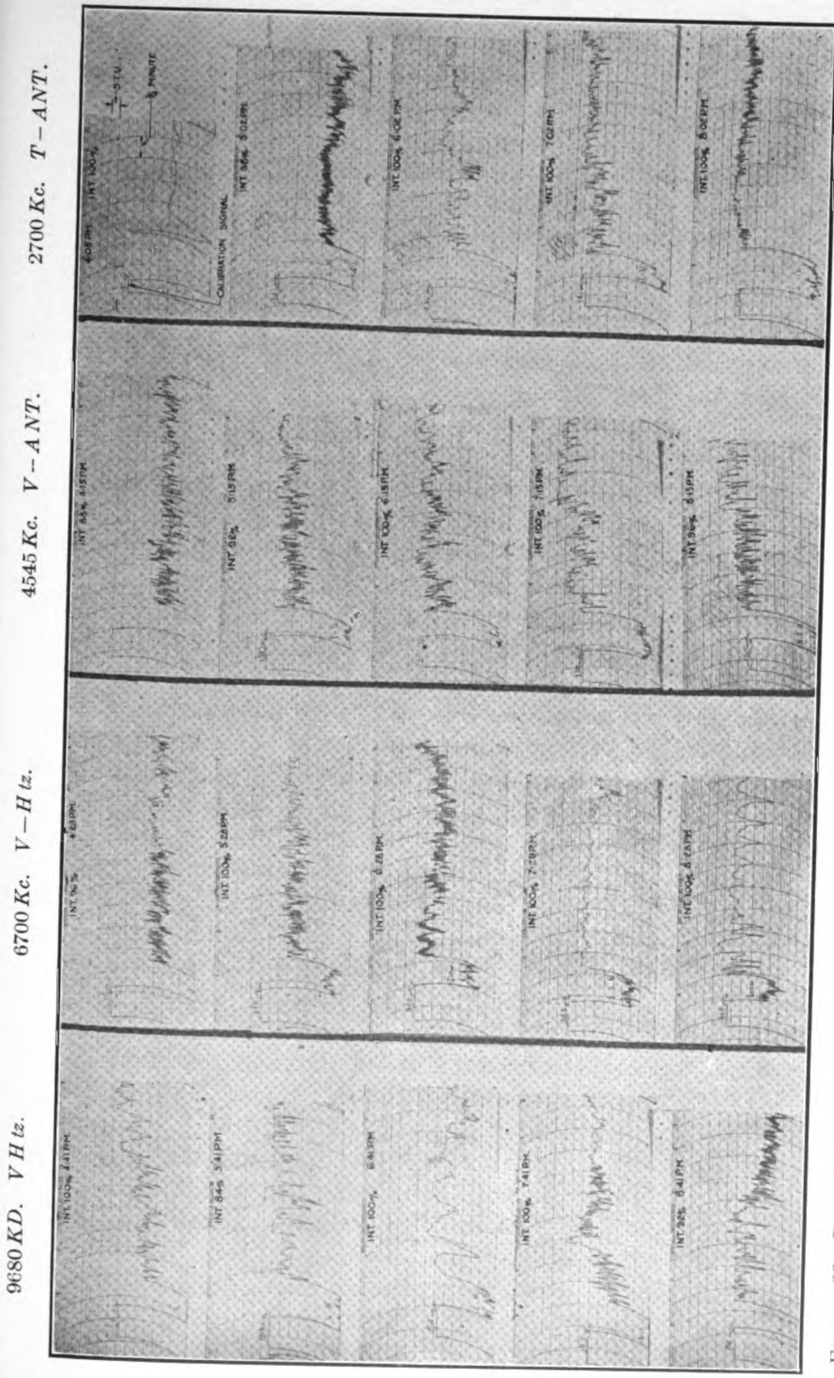

FIGURE 23—Records Showing Signal Strength and Fading Taken with Recorder at Columbus, Ga., Between 4:00 and 8:45 p. m., Dec. 15, 1925

several times a second, speech may be practically unintelligible.

When the fading is asynchronous, the quality may vary over a wide range. Some preliminary experiments indicate that single side band reception gives noticeably higher intelligibility and quality than ordinary double side band carrier reception under asynchronous fading conditions.

NOISE

There was very little trouble due to strays, although the measuring equipment had been made more sensitive than it was expected such strays would allow. Actual limit for the reception of signals was fixed by set noise.

TRANSMISSION FROM HORIZONTAL ANTENNAS

In the tests which have been described vertical antennas were employed at the transmitting station. In addition to these, however, tests in which a horizontal radiating conductor was used have been made at certain wavelengths. This form of radiator was originally provided for use in special experiments in which the usual "ground wave" is eliminated. A horizontal current above a plane perfectly conducting earth radiates scarcely anything in a horizontal direction, due to the fact that the effect of the image is equal and opposite to that of the antenna itself. Imperfect conductivity in the earth will, of course, increase the amount radiated horizontally, but there are good reasons for expecting that this will be quickly absorbed. The second reason for the use of a horizontal radiator lay in the possibility of its affording a more efficient antenna than the vertical type under certain conditions. It is the purpose of the present paper to discuss only the transmission features of this type of antenna and not its design.

It was soon found that there are times when the signal from the horizontal antenna is actually greater than that from the vertical antenna, the currents in both being equal. The fact that any signal is received at all at a point on the earth's surface at right angles to the antenna seems to be direct proof that there is, somewhere above the surface of the earth, a deflecting layer which is able to bend a wave, originally proceeding upward, so that it will return to the earth.

In Figure 25 are shown three pairs of records taken at Albertson and Quogue, Long Island, on a vertical loop or antenna at a frequency of 4.5 megacycles (66 m.). These are typical of

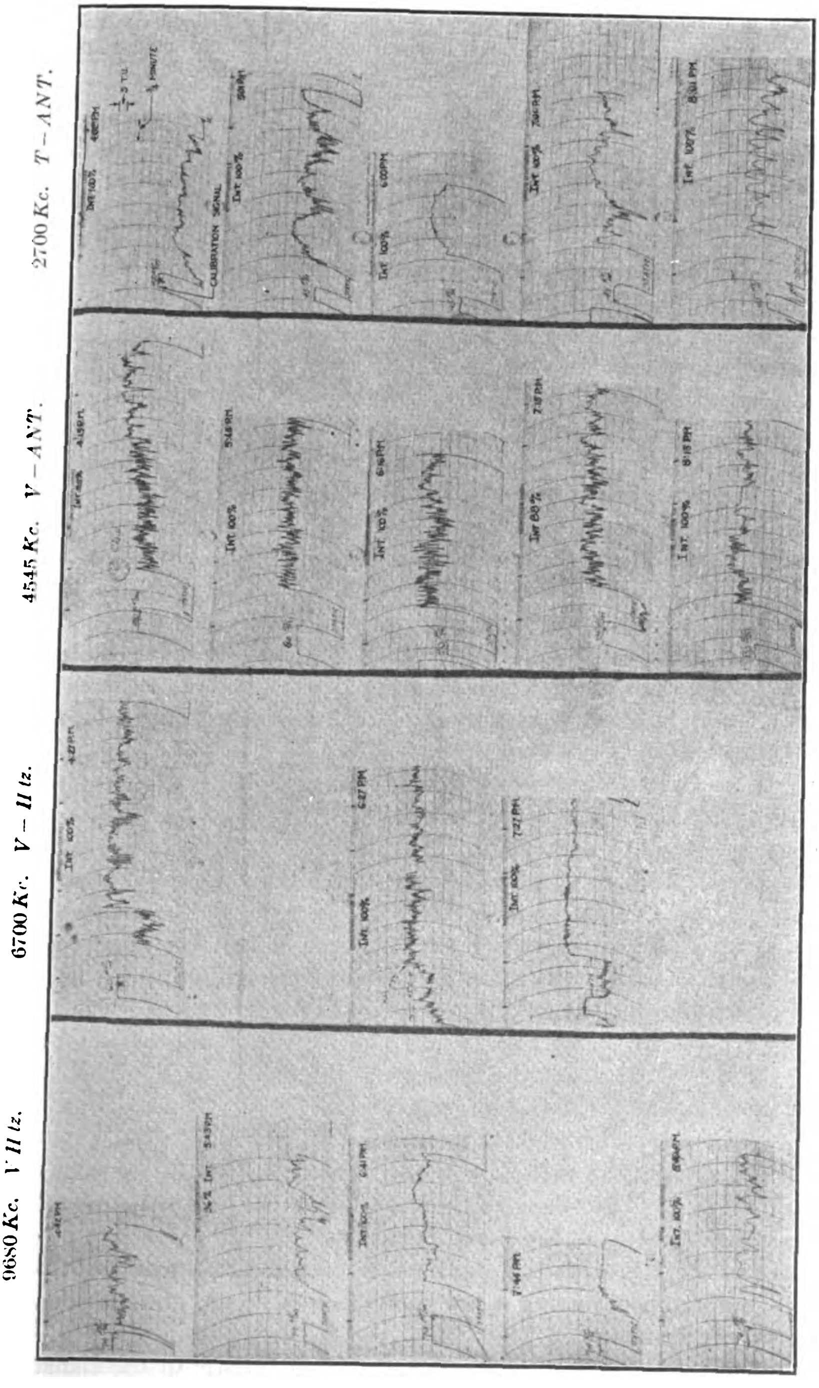

FIGURE 24—Records Showing Signal Strength and Fading Taken with Recorder at Bermuda at the Same Time as Records of Figure 23

what is observed at receivers which lie within the range of the ground wave. Records of both horizontal and vertical transmission are given so that a comparison may be made of the manner in which the signals fade in the two cases. The pair for 9:00 a. m., September 11 (Albertson), show that it is possible for the signal received from the vertical antenna to be constant at the same time that violent fading is obtained in that from the horizontal antenna. In this case the signal from the horizontal type changes from a value which is greater than that from the vertical to one which is less within three minutes. In the pair for 5:00 p. m., September 12 (Albertson), the maximum amplitude from the horizontal exceeds the maximum from the vertical by 19 T. U., or nearly ten times. Fading is also observed from the vertical antenna. At 1:00 p. m. on September 11 (Quogue), the signal from the vertical antenna was considerably lower in intensity than that from the vertical, and faded rapidly.

This difference in the character of signals from two types of antennas clearly shows that the signal is made up of components which are traveling along different paths. This evidence is obtained only when the receiver is not so distant that the ground wave is eliminated. For distant points, as will be shown later, these differences are not found and evidence for more than one path must be sought by other methods. Records have been taken at distant points but are not shown.

It is of interest to notice the differences which are found between these two types of radiators with respect to the shape of the curves which show diurnal variation. Such a comparison is made in Figure 26, which shows curves taken at various distances. At Long Beach, Albertson and Quogue, all less than 100 miles (161 km.) from the transmitter, the signal received from the vertical antenna is nearly constant throughout the whole 24 hours, indicating that the ground wave predominates. However, there are variations in average signal of approximately 20 T. U. (10:1), when the horizontal antenna is used. This is further evidence that the wave travels along two or more different paths. At Nantucket, a distance of 230 miles (380 km.), the signal from the vertical antenna varies considerably throughout the day. The shape of the curve from the vertical antenna resembles that from the horizontal antenna, although the variations in the latter are the greater. In each of these curves there is a minimum occurring a few hours before dawn, and also one shortly after noon.

The same shape of curve is thus characteristic of the signal

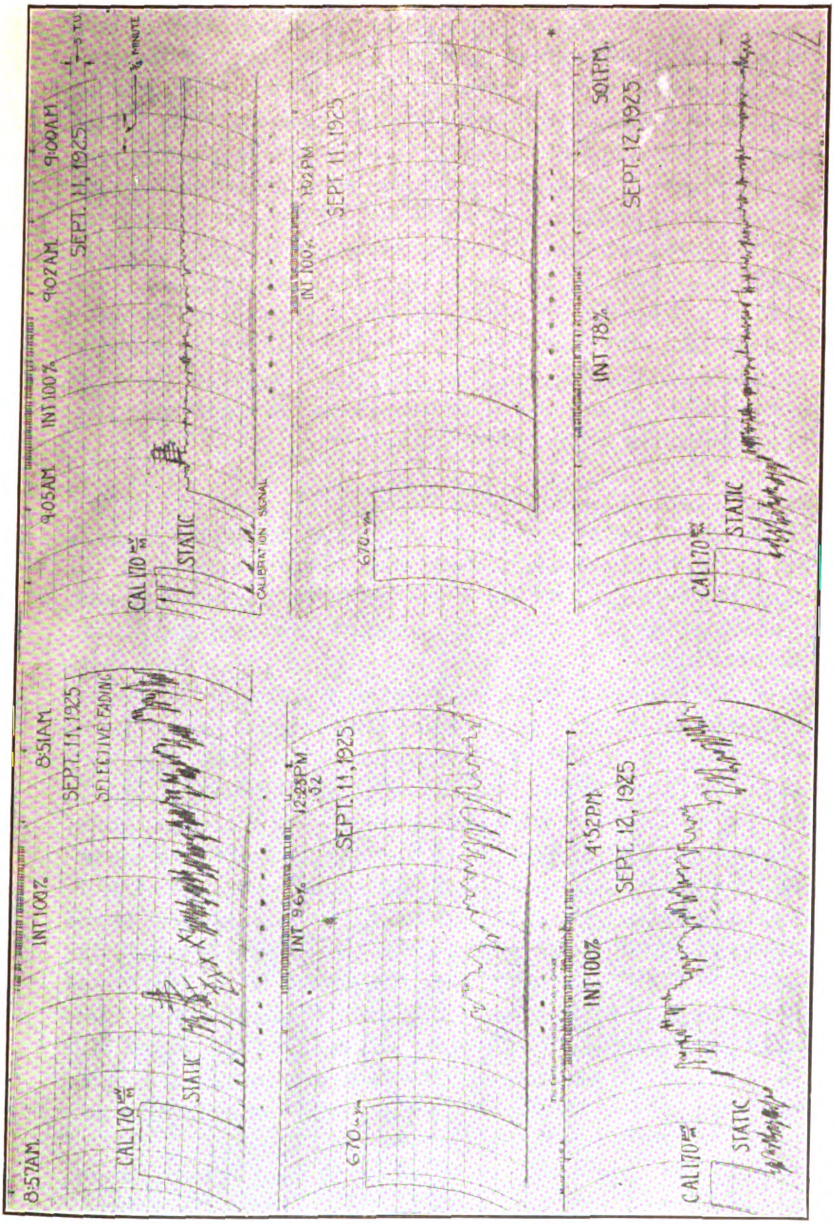

Figure 25—Comparison of Signals Received From Horizontal (left) and Vertical (right) Transmitting Antennas. First and Third Pairs of Records Were Taken at Albertson, 47 Miles, Second Pair Taken at Quogue, 90 Miles ← Time

received from the vertical antenna at moderate distances and that from the horizontal antenna at a nearby point. It is of interest to notice that at the more distant locations, Detroit and Minneapolis, the differences between signals from the two antennas disappear. This is evidence that the wave follows the same path to distant points regardless of the form of the transmitting antenna, and hence of its initial state of polarization. Since the radiation from the horizontal antenna must be primarily at an elevated angle, this indicates that the only signal from the vertical antenna that ultimately arrives at a distant point is that which is emitted at an angle above the horizontal.

One characteristic of these curves is that under the conditions of this experiment, the horizontal antenna is superior to the vertical at distances up to 100 or 200 miles in the early evening. On the other hand, the vertical antenna is more effective at noon and a few hours before sunrise.

Discussion of Results

It is not our purpose in the present paper to discuss in great detail the theoretical aspects of the short wave problem. It will be well, however, to note some of the more important points of contact between the quantitative results presented and certain theoretical ideas. Broadly speaking, most of the typical short wave characteristics may be interpreted in terms of the Eccles-Larmor theory of ionic refraction. The magneto-ionic theory is also of use in explaining phenomena at the upper boundary of the short wave region, and the work of Sommerfeld can be applied at distances for which the ground wave is of importance.

In considering transmission of the overhead wave, two somewhat related phenomena must be taken into account. One of these is absorption; the other is refraction. With respect to the former we may in most cases neglect that which is due to the ground. It is true, however, that the nature of the earth is of importance, both in transmission to nearby points and in cases of multiple "reflection." In other cases, when the signal fails it is interpreted as due either to absorption in the upper atmosphere, or to the absence of the proper ionization to produce the necessary bending of the wave.

Absorption is probably the cause of the daylight minimum, commonly found at frequencies below 7.5 megacycles (40 m.), and at such distances from the transmitter that the overhead wave dominates. It is possible that such absorption may play a part in producing the skip depression of the surfaces at nearby

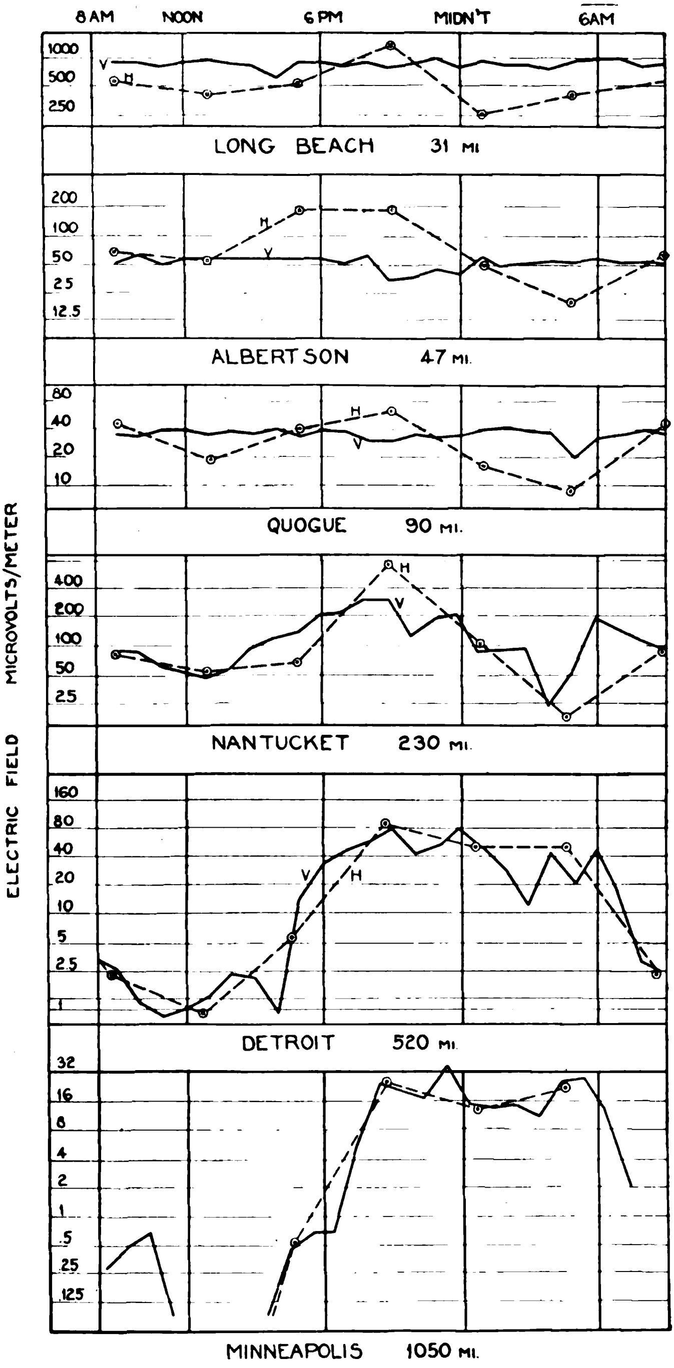

FIGURE 26—Diurnal Curves for Horizontal and Vertical Transmitting Antennas Compared

points, as suggested by E. V. Appleton, but we do not believe that it is the most important reason. The other explanation of the skip phenomenon assumes with Eccles (Electrician, vol. 71, 1913, pp. 969-970), that with increasing height the ionization increases, approaching a maximum value. Eccles showed that, under certain conditions, the index of refraction becomes zero and that this results in very abrupt bending, almost equivalent to reflection even with nearly normal incidence. (Elect. vol. 69, 1015.) He calculated trajectories for several assumed distributions of ionization and indicated that, with certain assumptions regarding the variations of refractive index, caustics and foci are found. The recent work of Hulburt has led to much more definite agreement between the theory and experimental results.

Reference has been made to the mass of qualitative evidence which has accumulated, indicating the existence of a skip effect. The quantitative data of the present paper confirms this position. As the frequency is increased the skip distance increases, appearing at first during the early hours of morning when recombination has reduced ionization below the value required for transmission. As the frequency increases the time during which the skip effect occurs increases, as should be expected from theory. In addition, the high degree of ionization which obtains during the day, becomes less harmful to the signal, a result predicted by the theory, which indicates that under similar conditions the absorption constant should be inversely proportional to the square of the frequency. Thus the signal is weakened during the night, but encounters better conditions during the day, a reversal of the trend at long wavelengths. At a distance of 800 miles, the frequency of 18 megacycles is so high that the noon-time ionization is just barely sufficient to produce the necessary bending. A small increase of frequency will probably cause the signal not to be heard at all during the 24 hours. This agrees roughly with the data of Taylor and Hulburt.

It is of interest to observe that the data checks the experiments of Taylor in the neighborhood of 4.5 megacycles, where the pronounced skip effect begins to take place, but there are some traces of the effect at even lower frequencies. It may be added that to a certain extent the skip depression is the result of the fact that the wave reaching the observing point is weak, regardless of which path it follows. If it travels over the ground path it will be greatly attenuated by absorption. If it follows the overhead path, the inefficiency of radiation of the vertical antenna at the high angle at which it must leave will make it

weak at the start. This effect, however, does not affect the results materially except perhaps at nearby points.

The frequency which can best be used for a particular service is a function of distance and time of day. The results of the present study indicate that for telephonic communication to distances of 200 miles, frequencies of 3 megacycles or less are the most useful of the short wavelength range, while distances of 500 miles call for about 6 megacycles. These frequencies will in general provide 24-hour service on a single wavelength. Continuous contact with stations at much greater distances in general requires a shifting of frequencies. Thus, for distances of 1,000 miles, frequencies of the order of 10 megacycles are of use during the day, while lower frequencies become preferable during the night and in fact are necessary at times.

For transatlantic communications the 3 megacycles wave is not of much use for telephony even at night when the radiated power is a few kilowatts. The reservation should be made, however, that this statement may not be correct when the single sideband transmission or directive radiation or reception is employed. It may be added that on those occasions when the signal has been strong at this frequency, the quality has usually been superior to that on the higher frequencies. During the day, frequencies of the order of 15 megacycles appear to be useful, although the indications are that 24-hour service will require a frequent shift of wavelength.

Credit for many valuable suggestions must be given the late Dr. H. W. Nichols, under whose direction this work was begun and largely carried out, and to Mr. J. F. Farrington, who made our early experiments and developed most of the present measuring equipment. It is evident from the scope of this work that the writers are acting as spokesmen for the group of engineers whose able and untiring participation in these experiments have made them possible.

SUMMARY: Quantitative data on field strength and telephonic intelligibility are given for transmission at frequencies between 2.7 megacycles (111 m.) and 18 megacycles (16 m.), and for distances up to 1,000 miles with some data at 3,400 miles. The data are presented in the form of curves and surfaces, the variables being time of day, frequency and distance. Comparisons are made between transmission over land and over water, between night effects and day effects, and between transmission from horizontal and from vertical antennas. Fading, speech quality and noise are discussed. The results are briefly interpreted in terms of current short wave theories.

THEORY OF DETECTION IN A HIGH VACUUM THERMIONIC TUBE*

By

Lloyd P. Smith

Some phases of the subject of detector action have been more or less vaguely understood in the past, due in part to the fact that the detector, as such, worked fairly well and all attention was turned to the amplification of the detected signal and to reproduction by means of the loud speaker. Amplifiers and loud speakers have been developed which reproduce the detected signal very accurately and so attention has been again centered around the detector. One common method of detection is by use of the high vacuum triode with the so-called grid leak and condenser, commonly called grid rectification. It is the mechanics of this method that will be discussed in this paper.

Effect Produced by Alternating E.M.F. on the Grid

In grid rectification the grid current-grid voltage characteristic of the tube is used. Three of these characteristic curves are shown in Figure 1, taken at plate voltages of 45, 90 and 135 volts. The reason that the grid current decreases when the plate potential is increased, with a constant grid potential, is that the electrons are given a higher velocity toward the plate and are not deflected from their path so easily with given grid potential and therefore fewer electrons strike the grid, and the grid current is consequently smaller.

Now let us investigate what takes place when the potential of the grid is varied. Suppose, for analysis, that we take a static characteristic as shown in Figure 2 and fix the grid potential at a value corresponding to the point a. If we impress an alternating *e.m.f.* on the grid of instantaneous magnitude e, and a maximum E, the grid potential will oscillate about the point a, an equal amount on either side, parallel to the voltage axis. Because of the shape of the characteristic the grid current will not oscillate symmetrically about the steady or continuous current I_c but will be distorted somewhat and displaced above the steady current

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line I_c. It is evident then that the average grid current will be increased by an amount ΔI_c. Since the potential a, impressed on the grid remains constant and the average grid current in-

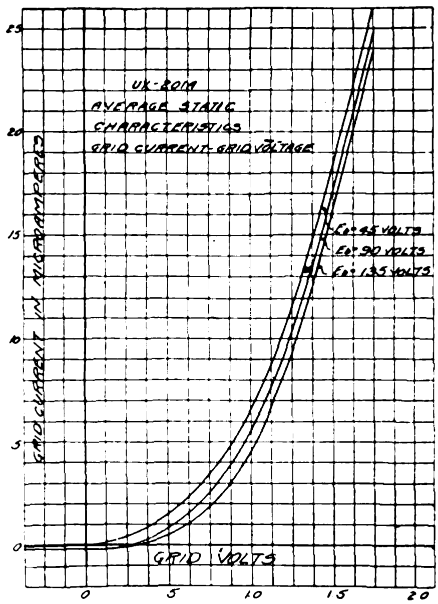

FIGURE 1

creases, a point b will be determined on a new or dynamic curve shown by the dotted curve. From this reasoning it would appear

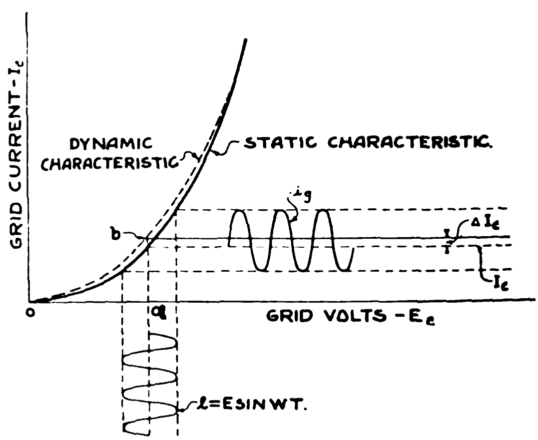

FIGURE 2

that such a dynamic curve would deviate from the static curve in the part where it had curvature—*i.e.*, where rectification took place—and approach the static characteristic where the curvature became inappreciable.

To verify this theory a static characteristic was taken on a UX 201-A tube with a constant plate potential of 45 volts and a filament potential of 5 volts. The range of grid potential covered was from 0 to +1.75 volts. Then with the same conditions two dynamic curves were taken, one with 100 millivolts and the other with 200 millivolts of approximately one million cycles radio frequency impressed on the grid. The results of these experiments are shown by the curves of Figure 3; together with additional dynamic curves corresponding to greater signal amplitude. As can readily be seen, the dynamic characteristics do depart from the static characteristic throughout the curved portion, and verify the preceding theory. From the spacing of these curves it is at once evident that the increase in current does not vary directly with the magnitude of the impressed radio frequency voltage.

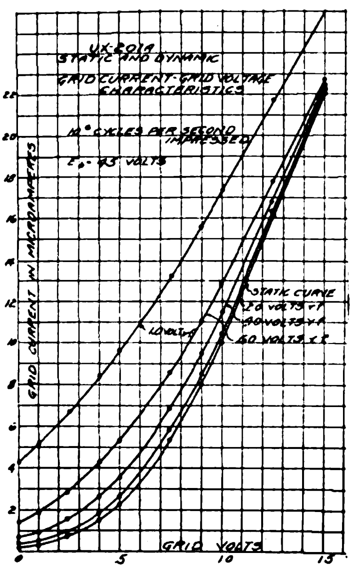

FIGURE 3

It will be interesting at this time to investigate the relation existing between the increase in grid current and the magnitude of the radio frequency *e.m.f.*, since for the static case the grid

current Ic is a function of the grid potential Ec, which will not be specified but will be represented as follows:

$$^*I_c = f(E_c) \qquad (1)$$

The instantaneous increase in grid current due to an instantaneous potential e on the grid is denoted by i_g, and the total grid current at any instant is

$$I_c + i_g = f(E_c + e) \qquad (2)$$

Expanding this by Taylor's theorem gives

$$I_c + i_g = f(E_c) + f'(E_c)e + f''(E_c)\frac{e^2}{2!} + f'''(E_c)\frac{e^3}{3!} + f''''(E_c)\frac{e^4}{4!} + \ldots \qquad (3)$$

Differentiating expression (1)

$$f'(E_c) = \frac{dI_c}{dE_c}$$

$$f''(E_c) = \frac{d^2I_c}{dE_c^2}\ etc.$$

and substituting these relations in (3) gives

$$I_c + i_g = f(E_c) + \frac{dI_c}{dE_c}e + \frac{dI_c}{dE_c^2}\frac{e^2}{2!} + \frac{d^3I_c}{dE_c^3}\frac{e^3}{3!} + \frac{d^4I_c}{dE_c^4}\frac{e^4}{4!} + \ldots \qquad (4)$$

But from equation 1, $I_c = f(E_c)$. Therefore the increase in grid current i_g is approximately as follows, using only the first four terms of the series

$$i_g = e\frac{dI_c}{dE_c} + \frac{e^2}{2!}\frac{d^2I_c}{dE_c^2} + \frac{e^3}{3!}\frac{d^3I_c}{dE_c^3} + \frac{e^4}{4!}\frac{d^4I_c}{dE_c^4} + \ldots \qquad (5)$$

Since e is a function of time and in this case assumed to be a simple sine function

$$e = E \sin wt$$

The average change, ΔIc, of grid current will be $\frac{1}{2}\pi$ times the integral of the right hand member of equation (5) from 0 to 2π. Substituting the value of e in (5) and integrating, expression 5 becomes

$$\frac{dI_c}{dE_c}\frac{1}{2\pi}\int_o^{2\pi} E \sin wt\, dt = o \qquad (6)$$

Integrating the second term gives

*J. C. Carson and J. H. Morecroft have given somewhat similar mathematical treatments, but without any relation to dynamic characteristics, and it therefore was thought necessary to carry out a mathematical development with this purpose in view.

$$\frac{d^2I_c}{dE_c^2}\frac{1}{2\pi}\int_o^{2\pi}\frac{E^2}{2!}sin^2wt\,dt=\frac{E^2}{4}\frac{d^2I_c}{dE_c^2} \tag{7}$$

Integration of the third term gives

$$\frac{d^3I_c}{dE_c^3}\frac{1}{2\pi}\int_o^{2\pi}\frac{E^3}{3!}sin^3wt\,dt=o \tag{8}$$

Integration of the fourth term gives

$$\frac{d^4I_c}{dE_c^4}\frac{1}{2\pi}\int_o^{2\pi}\frac{E^4}{4!}sin^4wt\,dt=\frac{E^4}{64}\frac{d^4I_c}{dE_c^4} \tag{9}$$

Adding (7) and (9) we obtain a very close approximation for the average increase in grid current, thus

$$\Delta I_c=E^2\frac{dE_c^2}{d^2I_c}+\frac{E^4}{64}\frac{d^4I_c}{dE_c^2} \tag{10}$$

From (10) it is seen that the average rectified current varies as the square and fourth power of the maximum input voltage. This is a fault inherent in rectification by curved characteristics and leads to distortion. Since the value of E in equation (10) is always small—usually very much smaller than 1—it is evident that the second term of equation (10) will be very small compared to the first and can be disregarded in all practical considerations. Therefore

$$\Delta I_c=\frac{E^2}{4}\frac{d^2I_c}{dE_c^2} \tag{11}$$

where the impressed voltage is a sine wave.

Effect of a Modulated E.M.F. on the Grid

Now let us extend this discussion to the case where a modulated wave is impressed on the grid. The instantaneous voltage of the ordinary modulated wave can be expressed mathematically as follows:

$$e=E\,cos\,pt\,(1+K\,cos\,qt) \tag{12}$$

where $E\,cos\,pt$ represents a wave of radio or carrier wave frequency and $EK\,cosqt$ is a wave of audio frequency. K is the ratio of the amplitude of audio frequency to that of the radio frequency and is a measure of the per cent modulation. When $K=1$, the amplitudes of the audio and radio frequency are equal and the resulting wave is said to be 100 per cent or completely modulated.

It is interesting to note what the instantaneous value of the increase in grid current, i_g, is, with a modulated wave of the form shown in equation (12). Substituting the value of e from equation (12) in equation (5), we have

$$i_g = \frac{d\,I_o}{d\,E_c}\left\{E\,cos\,p\,t(1+K\,cos\,q\,t)\right\} + \frac{d^2\,I_c}{d\,E_c^2}\left\{\frac{E^2}{2\,!}cos^2\,p\,t(1+K\,cos\,q\,t)^2\right\}+ \tag{13}$$

The remaining terms in equation (5) will be omitted, since they are very small and can be disregarded.

The first term in (13) does not contain a pure audio frequency term and will not be considered, as we are interested in the rectified audio component only. It will not give an increase in the average grid current.

The second term of (13) contains a direct current component as well as audio frequency components, which will be seen by expanding the second term as follows:

$$\frac{d^2\,I_c}{d\,E_c^2}\left\{\frac{E^2}{2\,!}cos^2\,p\,t(1+K\,cos\,pt)^2\right\} = \frac{d^2\,I_c}{d\,E_c^2}\,\frac{E^2}{2\,!}\begin{bmatrix} cos^2\,p\,t+2\,K\,cos^2\,p\,t\,cos\,q\,t \\ +K^2\,cos^2\,p\,t\,cos^2\,q\,t \end{bmatrix} \tag{14}$$

Expanding further we have

$$d\,g = \frac{E^2}{2\,!}\begin{bmatrix} \frac{1}{2}+\frac{1}{2}cos\,2\,p\,t+K\,cos\,q\,t+K\,cos\,2\,p\,t\,cos\,q\,t+ \\ \frac{K^2}{4}+\frac{K^2}{4}cos\,2\,q\,t+\frac{K^2}{4}cos\,2\,p\,t+\frac{K^2}{4}cos\,2\,p\,t\,cos\,2\,q\,t \end{bmatrix} \tag{15}$$

In this expression we are interested only in the direct current components and the audio frequency components, so we will disregard the radio frequency terms and those which represent the side band frequencies. The resulting expression for the direct current and audio components of grid current is

$$i_g = \frac{E^2}{2}\left[\left(\frac{1}{2}+\frac{K^2}{4}\right)+K\,cos\,q\,t+\frac{K^2}{4}cos\,2\,q\,t+\ldots\ldots\right]\frac{d^2\,I_c}{d\,E_c^2} \tag{16}$$

This equation gives a close approximation to the instantaneous increase in grid current. An analysis of this expression shows several interesting points—for instance, the first group of terms represents the direct current component of the increase in grid current; the second term, $K\,cos\,qt$, is the most important term for this is the change of grid current corresponding to the audio frequency impressed on the grid in the modulated wave. This term will be discussed in detail later. The third term, $\frac{K^2}{4}cos\,2\,q\,t$, represents the second harmonic of the audio frequency. This term is worthy of note, since if 100 per cent modulation is used

$K=1$ and the detected audio note will contain 25 per cent second harmonic.

Let us now consider what the relation is between the results derived above and the change in the dynamic characteristic of the tube. The average increase in grid current for the pure sine wave is given by equation (11). By inspection of the exprêssion it is at once evident that the increase in average grid current varies as the square of the impressed voltage, and this accounts for the increase in spacing between the dynamic characteristics shown in Figure 3. The effect of a modulated wave, of the form expressed in equation (12), on the tube characteristic is somewhat more complex. The average increase in the grid current will be given by integrating the right hand member of equation 15 over a long period of time. If this is done all of the cosine terms become zero and the average increase in grid current ΔI_c (modulated) becomes that corresponding to the first terms of equation (16), *e.g.*

$$\underset{(mod)}{\Delta I_c} = \left[\frac{E^2}{4} + \frac{E^2 K^2}{8}\right] \frac{d^2 I_c}{d E_c^2} \tag{17}$$

Now for the moment let us forget the cosine terms in equation 16, since they do not affect the average value of the grid current, and draw a characteristic of the tube in which the total grid current will be $I_c + \Delta I_c$. This is shown in Figure 4. It is clear

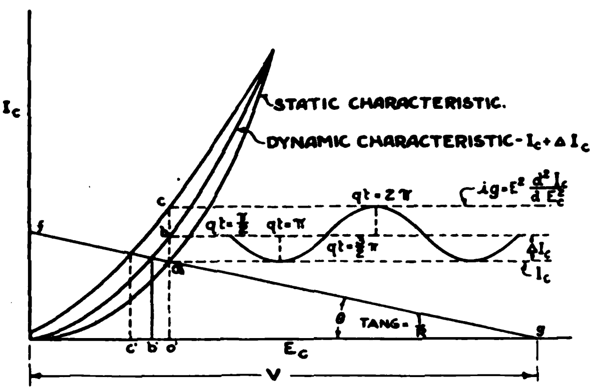

FIGURE 4

that the instantaneous value of the change in grid current, i_g, will oscillate about the average value of grid current, $I_c + \Delta I_c$. Suppose we impress a modulated wave on the grid with a definite grid potential a. The grid current will be increased by ΔI_c, and therefore will increase from the point a to be when $qt = \frac{\pi}{2}$ in

equation (16). When qt increases to π equation (16) becomes

$$i_g = \left[\frac{E^2}{4} + \frac{K^2 E^2}{8} - \frac{K E^2}{2} + \frac{K^2 E^2}{8}\right]\frac{d^2 I_c}{d E_c^2} \tag{18}$$

Now when the wave is 100 per cent modulated $K=1$, the right hand member of 18 reduces to zero and the grid current corresponds to the static value of I_c. Therefore between the values of qt equals $\frac{\pi}{2}$ and π the grid current decreases from b to a (Figure 4). Likewise when $qt = 2\pi$ the right hand member of (18) becomes $E^2 \frac{d^2 I_c}{d E_c^2}$, when $K=1$ and the grid current is increased from *a to c.* From this it is seen that the current varies periodically about the point b, between the static and dynamic characteristic through the point c. This is the phenomenon which takes place in the tube when a modulated wave is impressed on the grid without grid leak and condenser. There is obviously no change in the grid potential at an audio frequency, only an audio frequency change in grid current, *so there could be no change in plate current and therefore no detection.*

Function of Grid Leak and Condenser

In the case of detection with a grid leak and condenser the plate current decreases when the signal is impressed on the grid, and this occurs by a decrease in the grid potential. Referring to Figure 5, which is the ordinary grid lead and condenser circuit

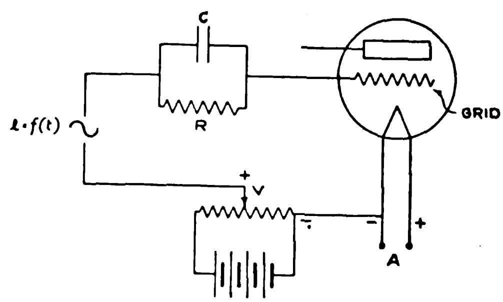

Figure 5

used with a high vacuum tube, it is evident that any increase in the direct current flowing to the grid must pass through the grid leak, R, which is a high resistance of about 1 to 10 megohms. In this circuit is an arrangement for varying the potential of the grid which makes it possible to operate the tube on any part of its characteristic—in other words, to vary the position of the

point a (Figure 4). The current passing through the grid leak R for any voltage V can be represented by the straight line fg (Figure 4) so that the intercept on the voltage axis corresponds to the value V and the slope $1/R$. This assumes, of course, that the resistance of the leak remains constant. Now suppose V is adjusted so that the line fg intersects the static characteristic at the point a. The intersection of the grid leak line and the static characteristic determines the initial value of the grid potential.

Then if a sine wave of radio frequency is impressed on the grid, such that it will produce an increase in grid current from a to b, this increase in average grid current must flow through the grid leak, causing an increased voltage drop across the leak, and therefore must follow along the grid leak line. The point of equilibrium will be at the point where the grid leak line fg and the dynamic characteristic through the point b intersect. This will decrease the grid potential from a' to b' and thus cause a drop in plate current. It is assumed that all of the radio frequency passes through the condenser as its reactance to high frequency is small compared to the large value of R. This explains why grid leak and condenser detection takes place with a decrease in plate current.

If a modulated wave be impressed on the circuit of Figure 5, such that the increase in average grid current is ΔI_c and the value of qt in equation (16) is equal to $\pi/2$, the grid current will come to the equilibrium point as before where the line fg intersects the dynamic characteristic through b. It was shown before that the grid current varied at an audio frequency made up of the fundamental and second harmonic, as shown in equation (16). Now since the capacity of the grid condenser C is very small—about .00025 microfarads—it offers a relatively high reactance to the audio frequency and it will be assumed for the present that all of the audio frequency passes through the grid leak. This varying current therefore must follow along the grid leak line fg at audio frequency. If the wave is 100 per cent modulated, $K=1$ and the limiting movement for one complete cycle of audio frequency is the intersection of the grid leak line fg with the static characteristic on one hand and its intersection with the dynamic characteristic through c. It is then clear that the potential of the grid must vary harmonically at audio frequency between the points a' and c'. It is this variation in grid potential that produces a corresponding change in plate current.

By inspection of Figure 4 it is evident that the greatest change in grid potential will take place when the grid leak line

approaches a horizontal position—*i.e.*, the value of R is increased and at the same time it must pass through the tube characteristics where they are the greatest distance apart. Thus a high value of grid leak can be used provided V is increased to a value such that the line will pass through the characteristics at the point where they are spaced farthest apart. Likewise for smaller values of R the slope of the line fg will be increased and V will have to be adjusted as before. A grid leak line corresponding to 1.5 megohms is fairly flat and very little is gained by increasing the grid leak resistance above this value excepting that it brings the line through the correct part of the characteristics when the value of V is fixed—*e.g.*, when the grid is returned to the positive side of the filament.

Experiments were made in which a radio frequency of approximately one million cycles per second was modulated 100 per cent by an audio frequency of 500 cycles per second. The circuit used was so arranged that the grid bias could be adjusted and the output of a tube could be measured for definite values of input voltage impressed on the grid. With this arrangement various values of grid leak were tried—from ¼ megohm to 10 megohms—and the potential of the grid was readjusted to give maximum output. In every case this was found to agree with a value determined by the slope of the grid leak line and the portion of the characteristics where the spacing was greatest—all of which shows that the grid potential should be adjusted to the point where the rate of change of slope of the grid characteristic is a maximum; *e.g.*, $\dfrac{d^2 I_c}{d E_c^2} = \text{maximum}$.

It is now necessary to make a modification of the change in grid potential due to the movement along the grid leak line to take into account the effect of the grid condenser. At very low frequencies the above explanation holds, but for high audio frequencies and their harmonics a considerable part of the audio frequency current passes through the condenser. In order to see the combined effect of the capacitance and resistance it will be best to investigate what happens in the case of a pure reactance alone. If we have a circuit with a pure reactance the combined effect of the current and voltage will be an ellipse as shown in Figure 6. If the capacity is reduced the effect is to make the ellipse more slender and vice versa. If a resistance is put in parallel with the condenser, the result will be to shift the ellipse with reference to the current and voltage axes. Figure 7 shows an ellipse due to capacity and a straight line due to a pure

resistance. To find the resultant path when a resistance and capacity are in parallel it is only necessary to add the currents, the voltage across them remaining constant. The resultant figure is shown in Figure 7. It should be pointed out that the resistance line does not coincide with the major axis of the resultant ellipse.

The case shown in Figure 7 is analagous to what happens in the grid leak and condenser. To determine the part played by

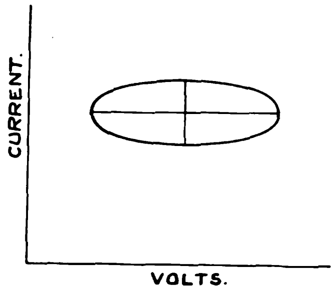

FIGURE 6

the condenser in conjunction with the tube characteristics we will refer to Figure 8, in which a section of the dynamic characteristic is shown on a large scale. In this case the ellipse due to the grid leak and condenser must remain tangent to the dynamic

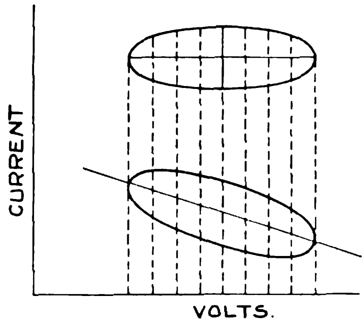

FIGURE 7

characteristic. Furthermore this ellipse is determined by the audio frequency change in the grid current, and it should be noted that it can not be a true ellipse because of the harmonics in the grid current. In this case the maximum change in grid potential is given by drawing lines $a\ a'$ and $b\ b'$ perpendicular to the voltage axis and tangent to the ellipse. This change is then $a'b'$.

It is evident that the ideal case would be to decrease the capacity and therefore make the ellipse approach the straight resistance line. In the practical case this is impossible because if the capacity is reduced the reactance to radio frequency is increased and the actual radio frequency voltage on the grid is very much reduced. If the capacity is increased or the audio frequency increased the effect is the same; the ellipse becomes broader or elongated in the vertical direction as shown in Figure 8 by the dotted ellipse, and the change in potential of the grid through one cycle of audio frequency is smaller than for a low capacity or low audio frequencies. This was verified by putting a variable condenser in parallel with the grid leak and the capacity

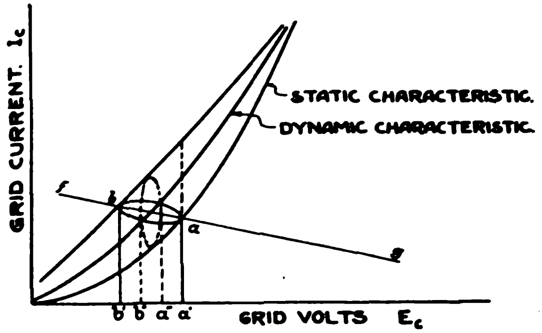

FIGURE 8

was varied from 50 to 500 micromicrofarads. It was found that the detector output increased rapidly until a capacity of 250 micromicrofarads was reached, then decreased less rapidly for large capacities. The reason for the small output at low capacities is the fact that the reactance to radio frequency causes a large drop in voltage across the condenser and the amplitude actually impressed on the grid is very small. After the 250 micromicrofarad capacity is reached the drop in output is due to the shifting of the ellipse as shown in Figure 8. There is also another capacity effect which causes a decrease in radio frequency voltage on the grid, and that is the interelectrode capacity of the tube. This produces somewhat the same effect as the grid condenser, but is much smaller. Thus it is seen that the grid leak and condenser method of detection produces frequency distortion.

From the preceding discussion it is evident that if the grid could be held at the correct initial potential good detector action could take place due to the capacity alone, since the capacity

alone gives an ellipse whose axes are parallel to the coordinate axes. In order to verify this a high inductance was placed in the circuit in place of the grid leak. The inductance was such as to offer a reactance of about 6 or 7 megohms to an audio frequency of 500 cycles, and at the same time the resistance to direct current was relatively very small. If plotted this would give a grid leak line very close to perpendicular to the voltage axis, so the effect of resistance could be neglected. The potential of the grid was adjusted by varying the grid bias so that the tube was operating on the correct part of the characteristic. This condition approached that of a pure reactance circuit and it was found that the output of the tube was slightly greater than for the case of a grid leak, with the proper bias.

From the foregoing it is quite evident that the amplitude of the detected signal will vary as a function of the frequency of modulation. Thus for high frequencies the effect is the same as increasing the capacity and thereby decreasing the amplitude of the audio change in grid potential—in other words, the output will be decreased.

To determine whether a change in plate potential produced an appreciable effect on the dynamic and static characteristics of the tube three grid current-grid voltage curves were taken at values of plate voltage of 50, 45 and 40 volts. These curves are shown in Figure 9. They are quite close together with a 5-volt

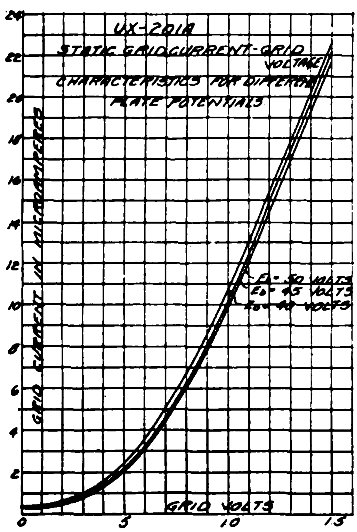

FIGURE 9

difference in plate potential and since the variation in plate potential is always very much smaller than this the effect can be disregarded as far as the preceding analysis is concerned.

The actual plate current produced by the variation in grid potential can be calculated but will be omitted here since it is not the purpose of this paper to enter into calculations of the plate circuit.

In conclusion the writer wishes to thank Mr. J. C. Warner and Mr. A. V. Loughren for their helpful suggestions in the preparation of this paper.

SUMMARY: In this paper some new ideas have been presented regarding tion by means of the high vacuum tube in connection with a grid leak and condenser with a grid leak and condenser, which show the function of the grid leak and condenser as well as their proper values for best detection. It has been shown that three main sources of distortion exist with this method of detection. They may be briefly stated as follows: Two sources from the curvature of the grid characteristic—one of which is frequently distortion due to the harmonics produced, and the other an amplitude distortion arising from the fact that the rectified grid current does not vary linearly with the input voltage. The remaining distortion is produced by the grid leak and condenser.

LONG DISTANCE RADIO RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE BUREAU OF STANDARDS IN 1925*

By

L. W. Austin

(Laboratory for Special Radio Transmission Research conducted jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy)

The following is a resume of the measurements made by the Bureau of Standards on long wave, long distance signal intensities and atmospheric disturbances during 1925, with the addition of some comparisons of the field intensities and disturbances from 1922 to the present time.

The method of measurement is the same as has been used in former years, except in the case of reception through disturbances considerably stronger than the signals which, as is well known, tend to reduce the apparent signal strength. The necessary correction under these circumstances is now determined for each individual case by observing an artificial signal of the same apparent strength as the signal being measured both with and without the disturbances. In this determination the artificial signal is introduced directly into the secondary of the receiver (not through the antenna) from a loosely coupled radio frequency generator.

In the first case, the antenna is coupled normally so that the disturbances are received with the artificial signal, then the antenna is replaced by an artificial antenna with exactly the same constants and coupling to the secondary so that the beat note remains unchanged in shifting from one to the other. A simpler method of correction described in the report for 1924 did not prove entirely satisfactory under all circumstances on account of variations in the character of the disturbances.

In April 1925, Dr. Dellinger, Chairman of the Committee on Measurements and Standards of the American Section of the U. R. S. I., requested the Radio Corporation of America and the Bell Laboratories to bring long-wave field intensity measur-

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ing apparatus to Washington for comparison with the apparatus used at the Bureau of Standards. The methods used by the two companies were alike in employing a radio-frequency comparison in which the signal being measured is matched by an artificial signal of adjustable intensity, produced by a local radio-frequency generator.

In the Bell Laboratories system[1] the current for the local signal is first measured and then attenuated in a resistance network and introduced into the coil antenna at its middle point across a 1-ohm resistance; while the Radio Corporation[2] regulates the intensity of the local signal and introduces it by means of a calibrated mutual inductance. The Radio Corporation method is of especial interest since it is identical in principle with the methods commonly used for radio field intensity measurement in England, France and Germany. At the Bureau of Standards, long-wave field intensities are measured with the telephone comparator[3] in which a known audio-frequency signal is matched against the signal as heard in the telephones of the receiving set. Special calibrations of the apparatus are made from time to time either by means of a local generator or from signals of known intensity. The agreement between the three systems of measurement was very satisfactory, when the disturbances were not too heavy; the differences being generally less than 20 per cent on distant signals, with still better agreement on the nearer stations.

The tables and curves[4] giving the results of the year's work at the Bureau of Standards are self explanatory. In addition to the data for 1925, the curves show also some comparisons of the field intensities of various stations and the strength of the atmospheric disturbances in former years.

The seasonal variations of the continental European stations as observed in Washington now seem to be fairly clear. The 10 A.M. observations give all daylight path conditions, though during the shortest days of winter the Nauen observations, with

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[1] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, vol. 11, p. 115; 1923.

[2] PROCEEDINGS OF RADIO ENGINEERS, vol. 11, p. 661; 1923.

[3] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, vol. 12, p. 521; 1924.

[4] The measurements are taken when possible on moderate speed transmission, as speeds above fifty words per minute are found to reduce the measured field intensity in a marked degree.

It is also to be noted that the two Ste. Assise stations formerly UFT and UFU are now FT and FU, while the old Nauen POZ is now AGS.

[5] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, vol. 14, p. 7; 1926.

6 hours difference of time, have to be taken somewhat before 10 A. M. The winter A. M. signals of the northern European stations are weak in America, owing either to the approach of sunset in Europe, or to the proximity of the arctic darkness along the signal path as suggested by Espenschied, Anderson and Bailey[5] or possibly to a combination of these causes. The 10 A. M. signals become in general stronger through the spring and summer and reach a distinct maximum about September, after which they fall to their low winter values. The course of the 3 P. M. signals which are transmitted at about 8 P. M.

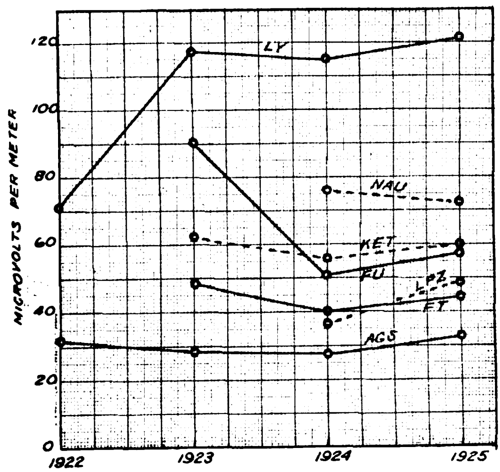

FIGURE 1—Annual Average Signal—10 A. M.—
for 1922, '23, '24, '25

in western Europe or 9 P. M. in central Europe and hence have a path of partial darkness during most of the year is the reverse of that of the 10 A. M. all daylight signals. The maximum occurs in mid-winter with a minimum in summer. The 10 A. M. and 3 P. M. curves cross each other as a rule in March and October. The 3 P. M. winter maxima are particularly strong in the case of the longer wave stations, Bordeaux LY, Ste.Assise FU, and Nauen AGW.

This strengthening of the 3 P. M. European signals in winter, with darkness extending over part of the signal path, does not seem to agree with the observations of Espenschied, Anderson and Bailey on signals between England and America, who found low intensities for partly dark signal path. We have, however, no observations on European stations of a wave length below

12,000 m., while the most pronounced drop in intensity as noted by the Bell observers was at much shorter wave lengths.

The west-east transcontinental signals from KET, Bolinas, California (three hours time difference), which have an all-daylight path during both observation periods show practical equality of the 10 A. M. and 3 P. M. signals in winter, while in summer the afternoon signals fall well below those of the morning. The same can also be said in regard to the signals of NAU,

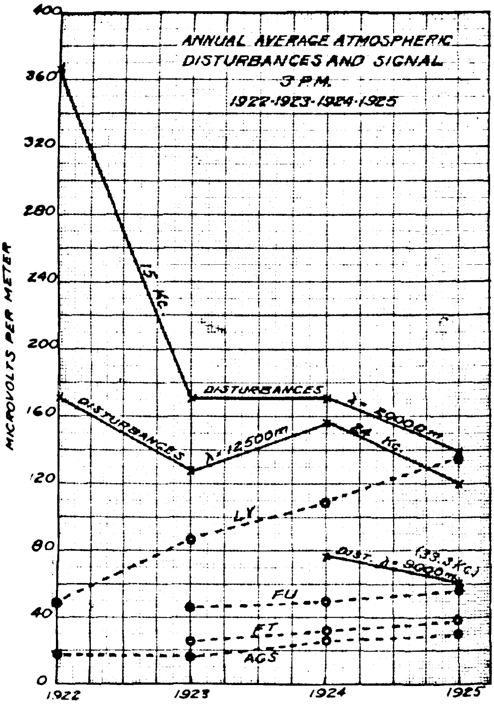

Figure 2

Cayey, Porto Rico (approximately south-north transmission) at a distance of 2,500 km. In the case of Monte Grande, Argentina, LPZ (south-north transmission) at a distance of 8,300 km. and with a little more than an hour's difference in time, there has been until recently no regular afternoon transmission. The morning signals from this station have shown no great seasonal variations, which was to be expected since the signal path is divided nearly equally between the northern and southern hemispheres. From the data available it seems that the afternoon signals are much weaker than those of the morning in

winter and spring, and it is probable that this difference persists throughout the year. The cause of this weakening of signals in the afternoon, which is observed on practically all stations in summer, even when there is comparatively little difference of time and no question of sunset or darkness effect, is not clear. It may be connected with absorption due to ionization in the lower atmosphere along the signal path, produced by the same

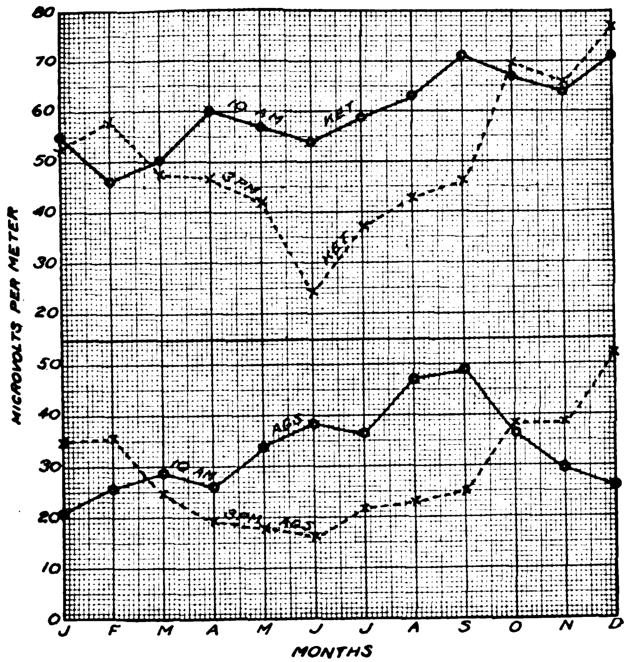

FIGURE 3—Nauen (A G S) and Bolinas (K E T)—Average Signal 10 A. M. and 3 P. M.. 1925

conditions which produce atmospheric disturbances in the afternoon along the same path[6].

In Figure 5, the monthly averages of the 3 P.M. signals from Bordeaux (LY) received in Washington and those of the corresponding signals taken at Meudon near Paris ($d = 510$ *km.*) are shown. The remarkable agreement in seasonal variation at these two receiving stations, which has not been observed in other signals taken at moderate and long distances, and which did not occur before LY's change of wave length from 23,400 m.

[6] Several years ago Navy operators in Panama reported weak signals from Washington whenever bad disturbance days occured in the eastern United States.

to 18,900 m., indicates that the variations observed in Bordeaux signals are due to causes in the neighborhood of the transmitting station and not in the general transmission paths. In addition to the agreement in seasonal variations at Washington and Meudon, it is to be noticed that there has been a gradual increase in Bordeaux's intensity at both receiving stations which is out of proportion to the average increase in antenna current.

During the year a slight modification has been made in the constants of the exponential term e^{-u} of the Austin-Cohen trans-

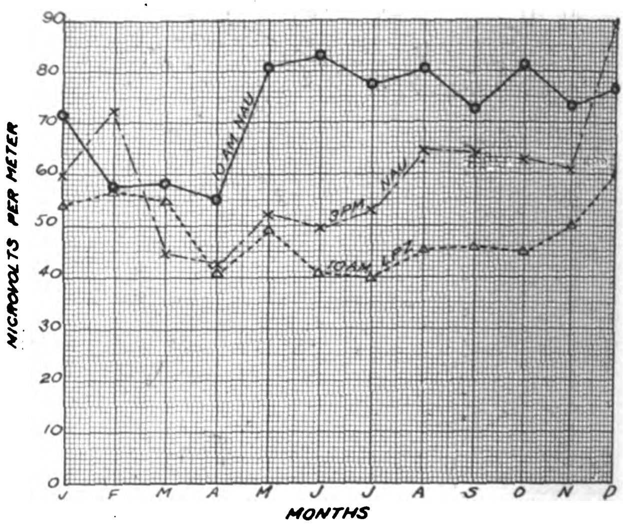

FIGURE 4—El Cayey (N A U) and Monte Grande (L P Z)—
Average Signal 10 A. M. and 3 P. M., 1925

mission formula, which has resulted in a great improvement in the agreement between the observed and calculated values at the greater distances without impairing the accuracy of the formula at moderate distances. The value of the exponent, u, expressed in km. and wave lengths, is now $\frac{1.4.10^{-3}d}{\lambda^{0.6}}$ instead of $\frac{1.5.10^{3}d}{\lambda^{0.5}}$, where d is the distance and λ the wave length, or expressed in km. and kc., $u = 4.57.10^{-5}d f^{0.6}$. This change approximately doubles the calculated values at 6,000 km. and increases them about four times at 12,000 km.

An examination is now being made of the transmission data already collected for the purpose of finding possible connections with other natural phenomena. Special study has been given to

possible meteorological relations. It appears that for long-distance long-wave transmission, for example between Europe and America, the connection between signal strength and American weather is not close. This is not remarkable since the meteorological data in America can apply to only a small portion of the signal path. A much more distinct relationship exists in transmission over a few hundred km. because in these cases the

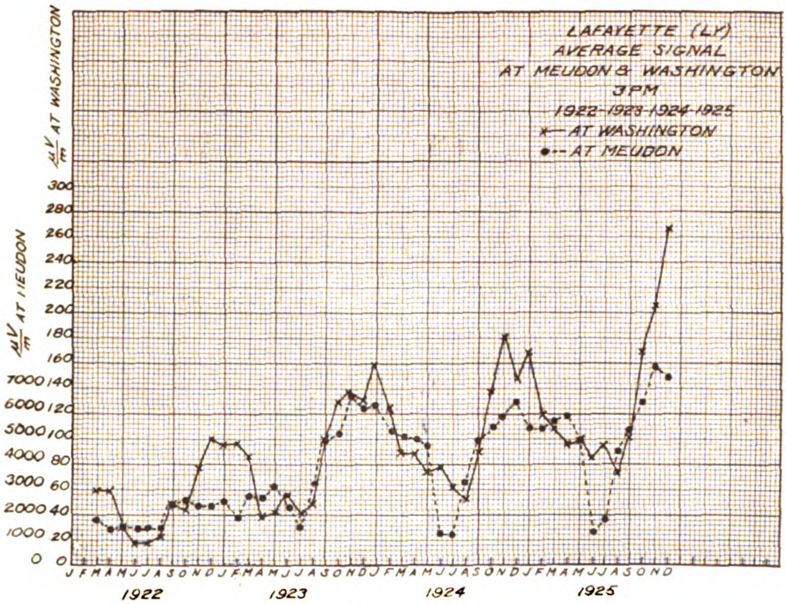

FIGURE 5

weather is comparatively uniform over the whole path. This will be discussed in a later report.

Comparisons have also been made between European signal intensity in Washington and the occurrence of sun spots[7] and magnetic storms. Thus far no certain relationship has been observed between sun spots and abnormal signals, but there appears to be in many cases an undoubted effect of the more severe magnetic storms upon transmission[8].

During the year directional measurements on the atmospheric disturbances were made at frequencies of 21.4 and 15 kc. (14,000

[7] For a complete study of the possible relationship between radio phenomena and solar activity observations covering at least one complete sun spot cycle will be necessary.

[8] Espenschied, Anderson and Bailey, loc. cit., have noticed in their measurements of signals between England and America that magnetic storms produce a marked decrease in night signals and a slight increase in day signals.

and 20,000 m.) at the U. S. Naval radio receiving stations at Colon and Balboa at the two ends of the Panama Canal.

The data obtained seem to warrant the following conclusions:

1. During the dry season, probably from January 15 to April 1, the atmospheric disturbances both at Balboa and Colon come almost entirely from the South American continent, *i.e.*, from the southeast.

2. When the dry season comes to an end and local storms begin to appear, the local disturbances from the low mountains

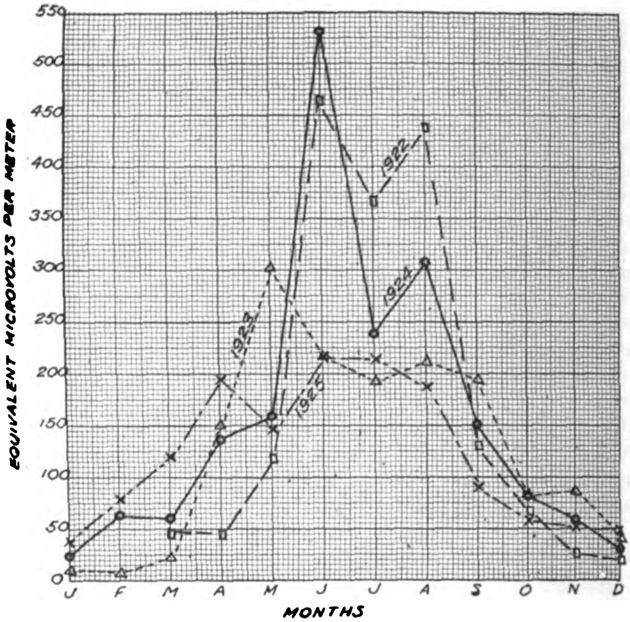

FIGURE 6—Average Atmospheric Disturbances, 3 P. M., 1922, '23, '24, '25—24 kc. (12,500 m.)

of the Isthmus begin to be prominent. This shifts the prevailing direction at Balboa at times from the southeast to the north, but has little effect on the direction at Colon since the mountains containing the local centers of disturbance here lie to the south and east, or roughly in the direction of the disturbance sources in Colombia.

3. In midsummer, while there is probably much disturbance from Central America and Mexico, the local disturbances from the Isthmus mask this to such an extent that the prevailing direction at Colon continues roughly southeast, while at Balboa the distant and local disturbances unite to give a northerly or northwesterly direction.

4. The observations further indicate that from northern sending stations, Balboa and Colon should give nearly equally good unidirectional reception in the dry season, but during the rest of the year, where the disturbance conditions are more troublesome, Colon should have considerable advantage over Balboa.

Observations in Washington show that in winter the prevailing afternoon disturbances come roughly from the southeast,

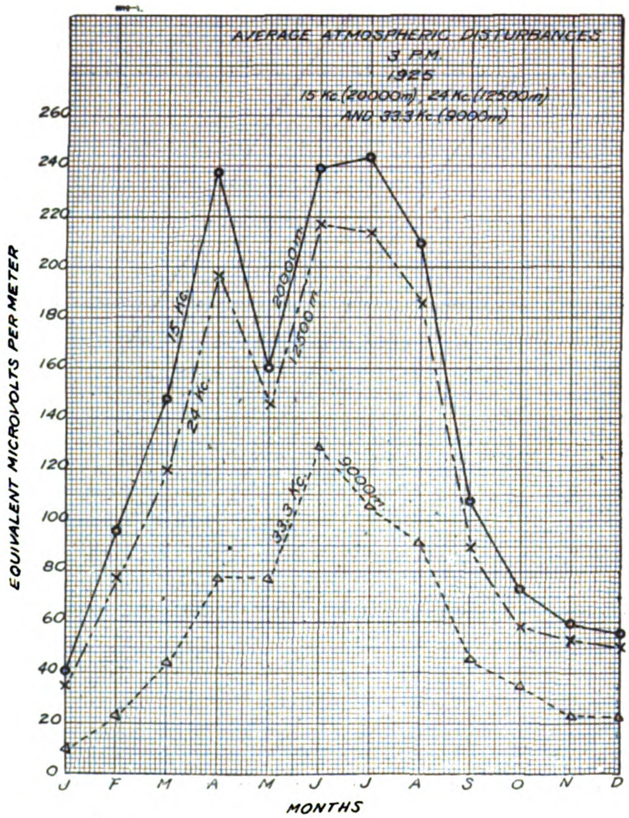

FIGURE 7

that is from the direction of eastern South America or perhaps in part from Africa. In summer the direction is southwesterly apparently from Mexico or the southwestern United States. This is in accord with the idea that disturbances generally originate over land and are most intense in the afternoon and evening in the regions where the sun passes very nearly overhead.

TABLE 1

Approximate Transmission Data

		Frequency f	Wave Length λ	Antenna Current I	Effective Height h	Distance d
LY*	Bordeaux	15.9	18900	540	180	6160
FU	Ste. Assise, Paris	15.0	20000	475	180	6200
FT	Ste. Assise, Paris	20.8	14400	380	180	6200
AGW*	Nauen, Berlin	16.5	18100	460	170	6650
AGS*	Nauen, Berlin	23.4	12800	400	130	6650
IDG	Pisa	14.2	21000	—	—	7300
KET*	Bolinas, San Francisco	22.9	13100	670	51	3920
LPZ	Monte Grande, Buenos Aires	23.6	12700	600	150	8300
GBL	Leafield, Oxford	24.4	12300	260	75	5900
NAU	Cayey, Porto Rico	33.8	8870	150	120	2490

* Daily antenna current reported.
Other antenna currents more or less uncertain.

TABLE 2

Average Signal Intensity and Atmospheric Disturbances for Lafayette (LY), Ste. Assise (FU) Nauen (AGW) and Pisa (IDG) in microvolts per meter.

1925	A. M. LY	A. M. FU	A. M. AGW	A. M. IDG	A. M. Dist.	P. M. LY	P. M. FU	P. M. AGW	P. M. IDG	P. M. Dist.
January	111.3	31.0	—	45.7	33.3	168.6	56.1	—	96.7	40.0
February	105.9	38.4	44.0	24.0	57.3	119.4	52.8	56.2	68.8	94.9
March	118.0	51.3	51.8	43.3	70.4	108.7	38.2	52.8	50.5	146.9
April	117.8	57.0	42.8	59.7	83.4	96.7	31.0	39.3	18.0	237.1
May	120.6	61.6	50.4	62.4	54.8	99.2	36.5	33.3	33.6	158.4
June	106.9	50.7	54.2	52.9	60.1	84.5	24.2	20.9	19.7	239.4
July	119.5	58.4	58.1	53.9	57.1	94.0	42.5	38.1	54.0	242.2
August	137.5	84.6	74.4	63.1	42.7	73.0	45.2	40.4	50.1	208.9
September	140.1	83.6	78.6	—	52.5	102.0	56.7	49.2	—	107.6
October	137.7	63.0	60.0	—	45.9	171.0	79.8	69.7	—	73.1
November	117.1	58.9	56.0	—	41.4	206.0	87.4	80.8	—	59.5
December	124.1	54.0	52.9	—	49.6	267.1	114.1	88.3	—	55.9
Average	121.2	57.4	56.6	50.6	54.0	132.5	55.3	51.7	48.9	138.6

TABLE 3

Average Signal Intensity and Atmospheric Disturbances for Ste. Assise (FT), Bolinas (KET) Nauen (AGS), Monte Grande (LPZ) and Leafield (GBL) in microvolts per meter

1925	A. M. UFT	A. M. KET	A. M. AGS	A. M. LPZ	A. M. GBL	A. M. Dist.	P. M. UFT	P. M. KET	P. M. AGS	P. M. PLZ	P. M. Dist.
January	31.9	54.2	20.0	54.2	—	26.0	44.8	52.4	34.7	—	35.6
February	35.6	45.4	24.6	57.1	—	44.5	35.8	56.7	35.1	—	76.2
March	36.9	49.4	27.1	55.7	--	56.8	29.4	48.0	24.4	26.8	119.1
April	44.8	59.2	24.7	41.8	—	67.3	28.0	45.9	18.8	19.7	194.2
May	46.1	56.4	32.9	49.0	15.5	46.2	27.5	41.9	17.4	23.5	145.0
June	46.8	53.7	37.5	40.2	17.9	51.3	18.5	23.4	16.0	—	217.4
July	45.4	58.0	35.8	39.9	19.6	42.5	28.6	36.6	21.4	—	213.0
August	53.1	62.1	46.5	45.6	23.2	32.7	28.0	43.0	22.9	—	185.5
September	50.6	70.6	48.6	45.9	21.7	38.7	33.3	46.5	24.7	—	88.2
October	47.5	66.7	35.8	44.9	21.5	38.7	46.2	69.5	38.5	—	58.5
November	41.6	63.0	28.1	50.7	17.1	34.0	56.7	65.0	38.5	—	52.2
December	48.5	70.4	24.1	60.3	23.6	41.6	71.3	78.0	49.2	—	48.5
Average	44.1	59.1	32.1	48.7	20.0	43.4	37.3	50.5	28.4	—	119.4

TABLE 4

Average Signal Intensity and Atmospheric Disturbances for El Cayey (NAU) in microvolts per meter

1925	A. M.		P. M.	
	NAU	Dist.	NAU	Dist.
January	71.1	9.5	59.3	8.5
February	57.2	15.3	72.2	22.6
March	58.2	22.0	44.2	44.0
April	55.1	25.6	42.4	77.9
May	80.3	28.6	52.4	77.4
June	83.3	25.7	49.1	129.1
July	77.6	28.1	52.1	104.5
August	80.2	15.0	65.0	91.8
September	72.2	22.1	63.9	46.1
October	81.5	26.1	62.6	35.0
November	73.0	16.5	60.7	23.0
December	77.0	21.2	89.7	22.5
Average	72.2	21.3	59.4	56.8

FIELD DISTRIBUTION AND RADIATION RESISTANCE OF A STRAIGHT VERTICAL UNLOADED ANTENNA RADIATING AT ONE OF ITS HARMONICS*

By

S. A. Levin and C. J. Young

((Radio Engineering Department, General Electric Company)

I. Introduction

Current and voltage distribution, electromagnetic field and radiation resistance are some quantities, among many, of interest in the investigation of an antenna. Their more or less complete and accurate determination is possible, mainly due to the works of H. Hertz[1] and M. Abraham.[2] The principles, given in these and other works, have here been applied to the investigation of an unloaded antenna consisting of a straight vertical wire radiating at one of its harmonics. The term "unloaded" is important. An antenna consists of a system of conductors, representing distributed capacities and inductances, which conductors are connected to one or more circuits with usually concentrated capacities and inductances. This is the general form of the loaded antenna. If the latter circuits are of negligible influence, or if no such circuits exist at all, then the antenna is unloaded.

Previously, similar calculations have been made by M. Abraham,[2] G. W. Pierce,[3] S. Ballantine,[4] H. Chireix,[5] and M. A. Bontch-Broojevitch,[6] among others. Since the present article contains added information, its publication has been thought justified, particularly at a time when all data on short wave radio transmission are of interest.

The antenna may be grounded or not and, in the latter case, its lower end may be at any distance above ground. The in-

*Received by the Editor, January 13, 1926. Presented at the New York meeting of The Institute of Radio Engineers, September 1, 1926.

[1] H. Hertz, Ges. Werke, v. II.

[2] M. Abraham, Phys. Zeitschrift, v. 2, 1901, p. 329.

[3] G. W. Pierce, "Electric Oscillations and Electric Waves," New York, 1920, p. 435, particularly p. 481.

[4] S. Ballantine, Proceedings of The Institute of Radio Engineers, v. 12, 1924, p. 823.

[5] H. Chireix, "Radioelectricité," v. 5, 1924, p. 65 (Bulletin Technique).

[6] M. A. Bontch-Broojevitch, "Electritchestvo, April, 1925, p. 228.

fluence of this distance upon the radiation resistance and field distribution has here been investigated for the first time, as far as is known to the authors. In making this treatment the earth has been assumed to be a perfect conductor.

II. Current Distribution

The current distribution assumed is indicated by Figures

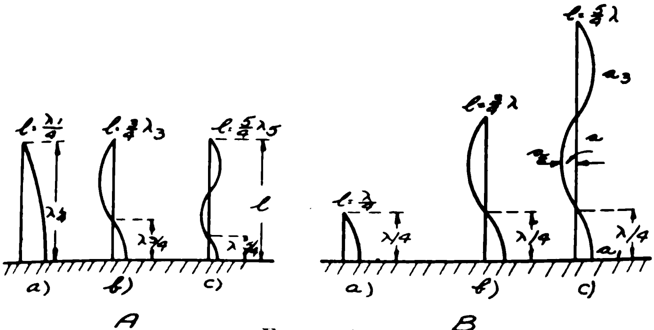

Figure 1

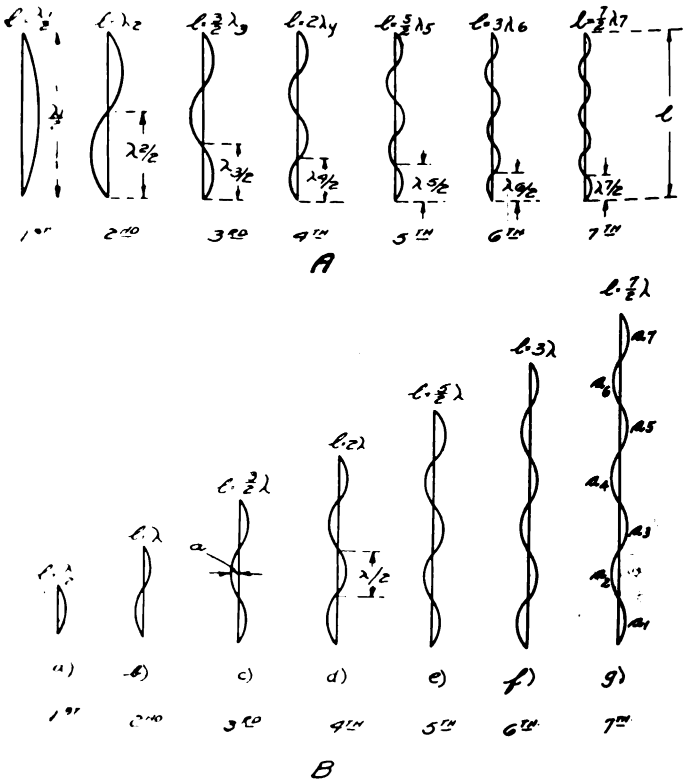

Figure 2

1 and 2, where all curves are of sine form. When the lower end is grounded—the grounded antenna—only odd harmonics are possible as shown in Figure 1, where the three first odd harmonics are indicated. At a constant operating wavelength λ, the height of the antenna depends upon the harmonic to be used (Figure 1, B). When the lower end is not grounded—the ungrounded antenna—it is possible to operate both at even and odd harmonics (Figure 2).

Analytically, the current distribution can be expressed in the following way, with reference to Figure 3. Let:

i = current value at the point x and the time t;
λ = operating wavelength;
I = length of the antenna wire;
$\lambda_o = 2\,I$ for the ungrounded antenna;
$\lambda_o = 4\,I$ for the grounded antenna;
c = the velocity of light.

Then:

$$\left.\begin{aligned} i &= -a \sin\frac{2\pi}{\lambda}\left(x-\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{\lambda}t \qquad x>0 \\ i &= a \sin\frac{2\pi}{\lambda}\left(x+\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{4}t \qquad x<0 \end{aligned}\right\} \quad (1)^7$$

for the ungrounded antenna, when λ_o/λ equals an odd integer;

$$\left.\begin{aligned} i &= -a \sin\frac{2\pi}{\lambda}\left(x-\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{\lambda}t \qquad x>0 \\ i &= -a \sin\frac{2\pi}{\lambda}\left(x+\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{\lambda}t \qquad x<0 \end{aligned}\right\} \quad (2)^7$$

for the ungrounded antenna, when λ_o/λ equals an even integer; finally,

$$i = -a \sin\frac{2\pi}{\lambda}\left(x-\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{\lambda}t \qquad x>0 \qquad (3)$$

for the grounded antenna, where λ_c/λ is an odd integer.

There is some theoretical justification for the assumption regarding this current distribution.[8] If the antenna is considered as a line with inductance L and capacity C per unit length, uniformly distributed, then

$$\left.\begin{aligned} \frac{\partial i}{\partial x} &= -C\frac{\partial v}{\partial t} \\ \frac{\partial v}{\partial x} &= -L\frac{\partial i}{\partial t} \end{aligned}\right\} \qquad (4)$$

[7] At $x=0$ the two values are equal.
[8] A. Guyau, La Lumière Électrique, tome XV (2° Série), 1911, p. 13. Balth van der Pol, jun., Jahrbuch der drahtlosen Telegraphie, v. 13, 1919, 217. K. W. Wagner, Archiv. für Elektrotechnik, v. 8, 1920, p. 145. Also M. Abraham, l. c.

where v and i are the instantaneous values of voltage and current, respectively. The losses are assumed negligible. The boundary conditions are:

$$i \text{ always} = 0, \text{ for } x = \pm \frac{l}{2} \tag{5}$$

in the case of an ungrounded antenna, but

$$\left. \begin{array}{l} i \text{ always} = 0, \text{ for } x = l \\ v \text{ always} = 0, \text{ for } x = 0 \end{array} \right\} \tag{6}$$

in the case of a grounded antenna. If the current i is assumed as in equations (1)—(3), then the first equation in the system

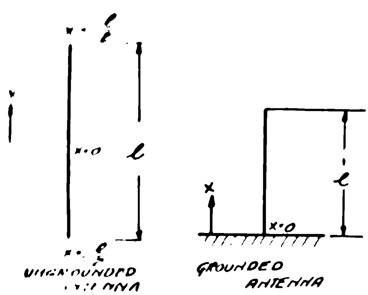

FIGURE 3

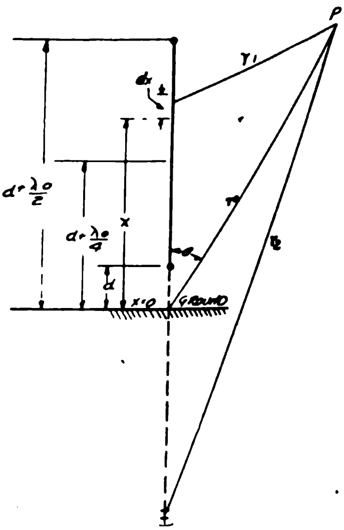

FIGURE 4

(4) is satisfied, if the voltage v is determined by integration of this equation. For instance, the voltage

$$v = \frac{a}{C\,c} \cos \frac{2\pi}{\lambda}\left(x - \frac{\lambda_0}{4}\right) \cos \frac{2\pi c}{\lambda} t + C(x) \qquad x > 0$$

corresponds to the current i in equation (3). The constant of integration $C(x)$ is in general a function of x but here equals zero, since v must equal zero when the current a equals zero. These values of v and i will be found to satisfy the proper boundary conditions and also the second equation in the system (4) if $LC = 1/c^2$, which well known relation can be supposed to be true in the cases under consideration. There are, of course, several

ways of treating the equations (4) with boundary conditions (5) or (6).

Though it is usual to assume a current distribution according to a sine law,[9] this is not always done.[10]

It is possible for an antenna to vibrate at several frequencies simultaneously. As an illustration, consider the grounded antenna. The expression

$$i = \sum_{n=1}^{n} -a_n \sin\frac{2\pi}{\lambda_n}\left(x-\frac{\lambda_o}{4}\right)\sin\left(\frac{2\pi c}{\lambda_n}t+\varphi_n\right)$$

for odd, integral values of $n = \lambda_o/\lambda$ (equation (3)) and the corresponding value of v, determined by integration of the first equation in the system (4), satisfy the boundary conditions (6) and also the second equation in the system (4), provived that $LC = 1/c^2$. Thus, the expression represents a possible current distribution. Usually one component is pronounced while all the others are very weak.

III. Electric Field

A. *Hertz Formula*—Consider an element of the antenna at a distance x above ground (Figure 4) and represent the current in it by

$$i = i_x \sin\frac{2\pi c}{\lambda}t \tag{7}$$

where i_x is a function of x. The electric field at a distant point P is

$$d\,e_1 = \frac{\sin\theta}{c^2 r_o}\ddot{f}\left(t-\frac{r_1}{c}\right),$$

where

$$\dot{f}(t) = \frac{\partial i}{\partial t}d\,x.$$

Thus

$$d\,e_1 = \frac{\sin\theta}{c^2 r_o} i_x\,d\,x\frac{2\pi c}{\lambda}\cos\frac{2\pi c}{\lambda}\left(t-\frac{r_1}{c}\right)$$
$$= \frac{2\pi}{c\,r_o\lambda} i_x\,d\,x\sin\theta\cos\frac{2\pi}{\lambda}(c\,t-r_1).$$

Assuming a perfect conducting earth,[12] the field due to the image is

$$d\,e_2 = \frac{2\pi}{c\,r_o\lambda} i_x\,d\,x\sin\theta\cos\frac{2\pi}{\lambda}(c\,t-r_2).$$

[9] M. Abraham, l. c.; G. W. Pierce, l. c.; S. Ballantine, l. c.; among others.
[10] M. Abraham, Annalen d. Phys., v. 66, 1898, p. 435.—A. Press, Proceedings of The Institute of Radio Engineers, v. 8, 1920, p. 441.—See also Encyklopädie der Math. Wissenchaften, v. V, 2, p. 483.
[11] See for instance, G. W. Pierce, l. c.
[12] M. Abraham, l. c., or G. W. Pierce, l. c.

The total field is

$$d\,e = d\,e_1 + d\,e_2,$$

which gives[13]

$$d\,e = \frac{4\,\pi}{c\,r_o\,\lambda}\,i_x\,d\,x \sin\theta \cos\frac{2\,\pi}{\lambda}(c\,t - r_o)\cos\left(2\,\pi\frac{x}{\lambda}\cos\theta\right) \tag{8}$$

because

$$r_o = \frac{r_1 + r_2}{2}, \quad r_2 - r_1 = 2\,x\cos\theta.$$

II *Ungrounded Antenna Operating at Odd Harmonics*—The lower end of the antenna may be at a distance $x = d$ above the ground as in Figure 4. The upper ene is then at a distance $x = d + \frac{\lambda_o}{2}$ above ground. From equation (1) is obtained, by a simple transformation of coordinates,

$$i_x = -a\sin\frac{2\,\pi}{\lambda}\left(x - d - \frac{\lambda_o}{2}\right) \tag{9}$$

for all points between $x = d + \frac{\lambda_o}{4}$ and $x = d + \frac{\lambda_o}{2}$;

and

$$i_x = a\sin\frac{2\,\pi}{\lambda}(x - d) \tag{10}$$

from $x = d$ to $x = d + \frac{\lambda_o}{4}$. a is equal to the current amplitude. The electric field at a distant point is by equation (8),

$$e = \frac{4\,\pi}{c\,r_o\,\lambda}\cos\frac{2\,\pi}{\lambda}(c\,t - r_o)\sin\theta\int_d^{d+\lambda_o/2} i_x\cos\left(2\,\pi\frac{x}{\lambda}\cos\theta\right)d\,x,$$

which with reference to equations (9) and (10), after elementary, but somewhat extensive calculations, gives for odd integral values of $\frac{\lambda_o}{\lambda} = n$.

$$e = \frac{4\,a}{c\,r_o}\cos\frac{2\,\pi}{\lambda}(c\,t - r_o)\cos\frac{2\,\pi}{\lambda}\frac{(\lambda_o + 4\,d)\cos\theta}{4}\sin\theta \times \times \frac{\cos\left(\frac{\pi}{2}n\cos\theta\right)}{\sin^2\theta} \tag{11}$$

For convenience let

$$\left.\begin{aligned} \alpha &= \frac{2\,\pi}{\lambda}\,\frac{\lambda_o + 4\,d}{4} = \frac{\pi}{2}n\left(1 + \frac{4\,d}{\lambda_o}\right) \\ \beta &= \frac{\pi}{2}n \\ \gamma &= 1 + \frac{4\,d}{\lambda_o} \\ \alpha &= \beta\,\gamma, \end{aligned}\right\} \tag{12}$$

[13] See also Balth van der Pol, jun., l. c.

where n may be odd or even.
Then

$$e=\frac{4a}{c\,r_o}\cos\frac{2\pi}{\lambda}(c\,t-r_o)\cos(\beta\,\gamma\cos\theta)\sin\theta\frac{\cos(\beta\cos\theta)}{\sin^2\theta}. \quad (13)$$

C. *Ungrounded Antenna Operating at Even Harmonics*—Similarly, when n is an even integer

$$e=-\frac{4a}{c\,r_o}\cos\frac{2\pi}{\lambda}(c\,t-r_o)\sin(\beta\,\gamma\cos\theta)\sin\theta\frac{\sin(\beta\cos\theta)}{\sin^2\theta} \quad (14)$$

D. *Grounded Antenna*

$$e=-\frac{2a}{c\,r_o}\cos\frac{2\pi}{\lambda}(c\,t-r_o)\frac{\cos(\beta\cos\theta)}{\sin\theta}, \quad (15)$$

where n is an odd integer, and the limits of integration are now zero and $\frac{\lambda_o}{4}=i$.

E. *Power Distribution Curves*—The numerical value of the Poynting vector[14] is $\frac{c}{4\pi}e^2$, where e can be obtained from the equations (13)(15). Since only relative values of this vector are of interest here, the factor $\cos\frac{2\pi}{\lambda}(c\,t-r_o)$ may be omitted in the evaluation of e^2, as at a given moment it has the same value at all points. If in a polar diagram the length of the radius vector, corresponding to the angle θ, is made proportional to e^2, then

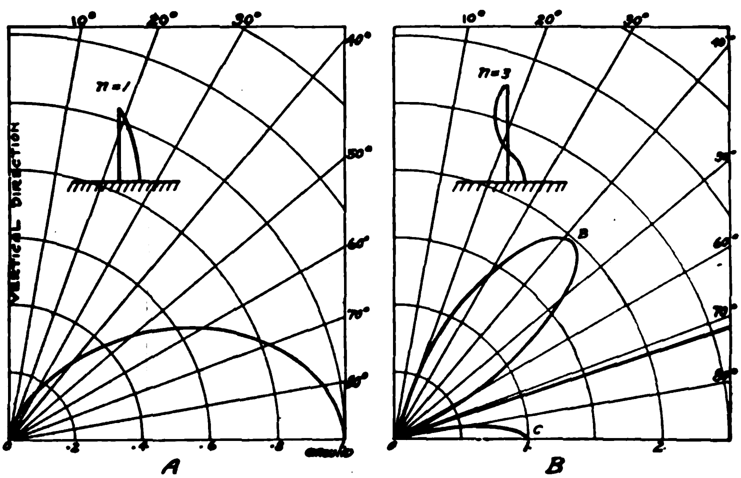

FIGURE 5

[14] See for instance, Pierce, l. c.

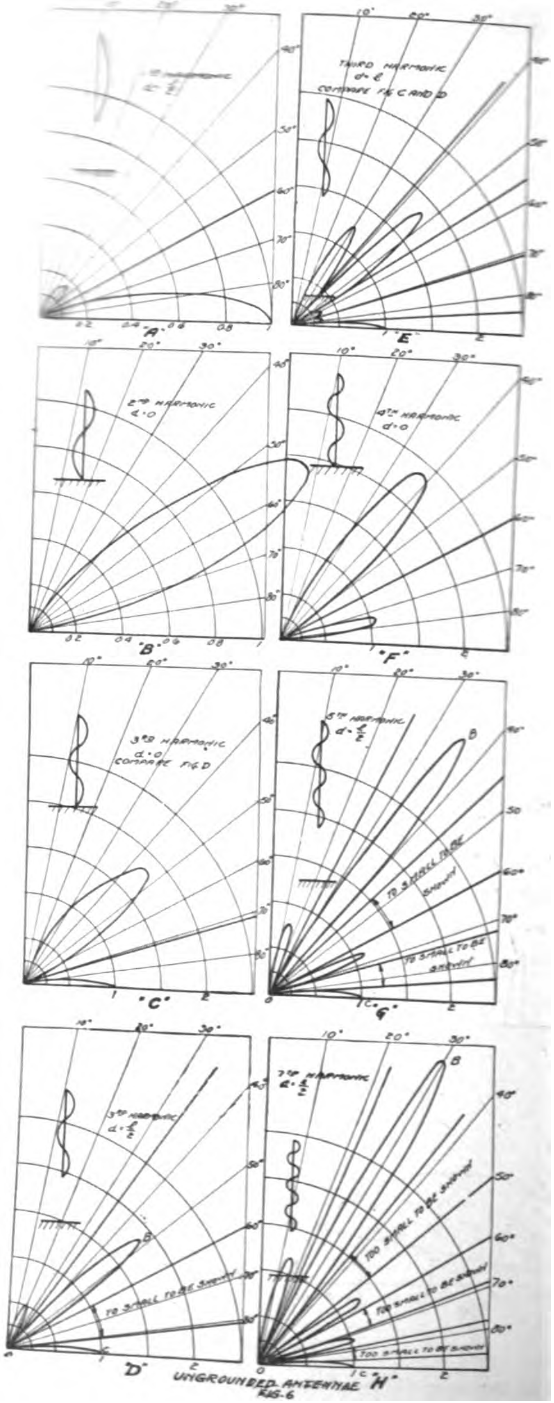
THIRD HARMONIC
d = ℓ
COMPARE FIG C AND D
2ND HARMONIC
d = 0
4TH HARMONIC
d = 0
3RD HARMONIC
d = 0
COMPARE FIG D
5TH HARMONIC
TO SMALL TO BE SHOWN
3RD HARMONIC
TO SMALL TO BE SHOWN
7TH HARMONIC
TOO SMALL TO BE SHOWN
"A"
"B"
"C"
"D"
"E"
"F"
"G"
"H"
UNGROUNDED ANTENNAE
FIG-6

Figure 6

the locus of its end point is a curve, which may be called the power distribution curve. See Figures 5-6, which are self-explanatory.

IV. Radiation Resistance

A. *Power Radiated by the Ungrounded Antenna at Odd Harmonics*—In order to obtain the radiated power p,[12] multiply $\frac{e}{4\pi}e^2$ by the surface element $d\,s=2\pi\,r_o^2\,\sin\,\theta\,d\,\theta$ and integrate from $\theta=0$ to $\theta=\frac{\pi}{2}$. This gives

$$P=\frac{8a^2}{c}S_1\cos^2\frac{2\pi}{\lambda}(c\,t-r_o), \tag{16}$$

where

$$S_1=\int_o^{\pi/2}\cos^2(\beta\,\chi\,\cos\theta)\frac{\cos^2(\beta\cos\theta)}{\sin\theta}d\,\theta \tag{17}$$

or

$$S_1=\frac{1}{2}\int_o^2\frac{\cos^2[\alpha(z-1)]\sin^2\beta\,Z}{Z}dZ, \tag{18}$$

as will be shown briefly. Note that $\alpha=\beta z$ and put $U=\cos\,\theta$

Then

$$S_1=\frac{1}{2}(S_{11}+S_{12})$$

where

$$\left.\begin{aligned} S_{11}&=\int_o^1\frac{\cos^2(\alpha\,U)\cos^2(\beta\,U)}{1+U}dU\\ S_{12}&=\int_o^1\frac{\cos^2(\alpha\,U)\cos^2(\beta\,U)}{1-U}dU\end{aligned}\right\}$$

Consider first S_{11}. Since

$$\left.\begin{aligned}\alpha\,U&=\alpha\,(1+U)-\alpha\\ \beta\,U&=\beta(1+U)-\beta\end{aligned}\right\}.$$

the transmission $1+U=Z$ gives

$$S_{11}=\int_1^2\frac{\cos^2[\,\alpha\,(\alpha-1)]\cos^2[\beta(Z-1)]}{Z}dZ$$

But $\beta=\frac{\pi}{2}n$, where n is an odd integer. Thus

$$\cos[\beta(Z-1)]=\pm\,\sin\beta\,Z.$$

$$S_{11}=\int_1^2\frac{\cos^2[\alpha(Z-1)]\sin^2\beta\,Z}{Z}dZ.$$

Finally, the substitution $U=-V$ gives

$$S_{12}=\int_{-1}^0\frac{\cos^2(\alpha\,V)\cos^2(\beta\,V)}{1+V}dV.$$

which is of the same form as S_{11} and is found equal to

$$S_{12}=\int_0^1 \frac{\cos^2[a(Z-1)]\,\sin_2\beta Z}{Z}\,dZ.$$

B. Power Radiated by Ungrounded Antenna at Even Harmonics.

$$P=\frac{8\,a^2}{c}S_2\cos^2\frac{2\pi}{\lambda}(c\,t-r_o), \tag{19}$$

where

$$S_2=\int_0^{\pi/2}\sin^2(\beta\,\gamma\cos\theta)\,\frac{\sin^2(\beta\cos\theta)}{\sin\theta}\,d\theta, \tag{20}$$

or

$$S_2=\frac{1}{2}\int_0^2\frac{\sin^2[a\,(Z-1)]\sin^2\beta Z}{Z}\,dZ. \tag{21}$$

C. Power Radiated by Grounded Antenna

$$P=\frac{2\,a^2}{c}S_3\cos^2\frac{2\pi}{\lambda}(c\,t-r_o), \tag{22}$$

where

$$S_3=\int_0^{\pi/2}\frac{\cos^2\left(\frac{\pi}{2}n\cos\theta\right)}{\sin\theta}\,d\theta, \tag{23}$$

or

$$S_3=\frac{1}{2}\int_0^2\frac{\cos^2\frac{\pi}{2}n\,(Z-1)}{Z}\,dZ. \tag{24}$$

D. Radia ion Resistance—The time average of

$$\cos^2\frac{2\pi}{\lambda}(c\,t-r_o)$$

in the equations (16), (19) and (22) is equal to ½. The time average of the current square is equal to $\frac{1}{2}a^2$. The radiation resistance[12] R may be defined as the time average of the power divided by $\frac{1}{2}a^2$. Thus:

$$R=\frac{\frac{8\,a^2}{c}\,\frac{1}{2}\,S_1}{\frac{1}{2}a^2}=\frac{8\,S_1}{c}$$

or

$$R=240\,S_1 \text{ ohms} \tag{25}$$

for an ungrounded antenna operating at odd harmonics. At even harmonics

$$R=240\,S_2 \text{ ohms} \tag{26}$$

For the grounded antenna

$$R=60\,S_3 \text{ ohms} \tag{27}$$

The definite integrals S_1 and S_2 have been computed and are plotted in Figure 7, which allows the calculations of the radia-

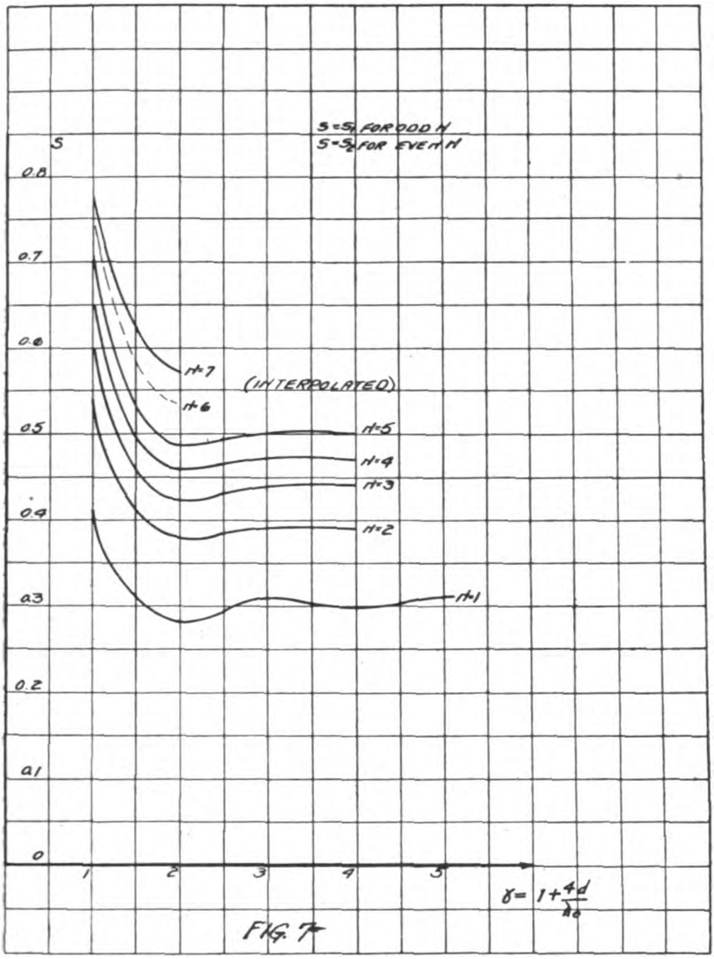

FIGURE 7

tion resistance for an ungrounded antenna up to the 7th harmonic and for various distances above ground.

Examples:

(1) $n=1$ and $d=0$;

$\therefore$ $\gamma=1$ and $S_1=0.41$;

$\therefore$ $R=240\times 0.41=98.4$ ohms.

(2) The same as above but $d=i$;

$$\therefore \quad \gamma=1+\frac{4\,d}{\lambda}=1+\frac{4\,i}{2\,i}=3 \text{ and } S_1=0.31;$$

$$\therefore \quad R=74.4 \text{ ohms.}$$

The integral S_3 has also been evaluated for odd values of n. The value of $R=60\,S_3$ is shown in the following table.

TABLE 1

Harmonic (n)	Rad. Res. (ohms)	
1	37	
3	52	
5	60	
7	65	
9	68	
11	71	
13	73	15
15	75	
17	77	
19	79	
21	81	

The solution of the problem rests on the evaluation of the integrals (18), (21) and (24 and it seems worth while to give briefly the method used in calculating them.

$$S_1=\frac{1}{2}\int_0^2 cos^2\left[\frac{\pi}{2}n\,\gamma\,(Z-1)\right]\frac{sin^2\frac{\pi}{2}n\,Z}{Z}\,dZ,$$

n being here an odd integer and γ greater than or equal to unity. For a given n, S_1 has to be found for $\gamma=1$, 2, 3, etc. The process has to be repeated for different values of n. Then the curves of Figure 7, corresponding to n odd, are obtained. For a given n and γ, the value of S_1 can be determined thus. Calculate the values of Z, between and including zero and two, at which

$$sin^2\frac{\pi}{2}n\,Z=0 \text{ and } cos^2\left[\frac{\pi}{2}n\,\gamma\,(Z-1)\right]=0.$$

The function under the sign of integration is equal to zero for all these Z-values. Example: $n=3$, $\gamma=3$. The zero points are $Z=0, \frac{2}{7}, \frac{4}{9}, \frac{6}{9}, \ldots\ldots \frac{18}{9}=2$. Take, for instance, $\frac{1}{6}\times\frac{1}{9}=\frac{1}{54}$ as interval, that is, calculate for $n=3$, $\gamma=3$,

$$cos^2\left[\frac{\pi}{2}n\,\gamma\,(Z-1)\right]\frac{sin^2\frac{\pi}{2}n\,Z}{Z}$$

[16] These values are interpolated.

at $$Z=0, \frac{1}{54}, \frac{2}{54}, \ldots\ldots \frac{108}{54}=2.$$

Add all these calculated values. In this example, the sum equals 49.587. Then is

$$S_1=\frac{1}{2}\left(\frac{2}{108}49.587\right)=0.46.$$

Since $$sin^2[a(Z-1)]=1-cos^2[a(Z-1)],$$

$$S_2=\frac{1}{2}\int^2\frac{sin^2\beta Z}{Z}dZ-\frac{1}{2}\int_o^2\frac{cos^2[a(Z-1)]sin^2\beta Z}{Z}dZ.$$

The last integral is calculated for n even exactly as the integral S_1 for n odd. The first integral is independent of γ. Its value for $n=2$ or other even n-values is obtained as above, if the points at which $\frac{sin^2\beta Z}{Z}=0$ are determined.

Finally, S_3 is found after determination of the points at which

$$\frac{cos^2\frac{\pi}{2}n(Z-1)}{Z}=0.$$

The values

$$\frac{sin^2\frac{\pi}{2}nZ}{Z},\quad \frac{sin^2\beta Z}{Z}\quad\text{and}\quad\frac{cos^2\frac{\pi}{2}n(Z-1)}{Z}\quad(n\text{ odd}),$$

considered above, have at $Z=0$ the form $\frac{0}{0}$, but a definite limit exists and is equal to zero. It is easy to see that the functions to be integrated, see equations (18), (21) and (24), are continuous at all points, including zero and are thus integrable.

V. Voltage

Since the maximum antenna voltage is of interest in the determination of corona, insulation, etc., its estimation will be illsutrated briefly for the case of an ungrounded antenna operating at odd harmonics. The first equation in (4), symbolically written, gives

$$\frac{\partial i}{\partial x}=-j\omega CV=-j\frac{2\pi c}{\lambda}CV,$$

where i and V may be the maximum values at the point x. From equation (1) is obtained

$$i=\mp a\,sin\frac{2\pi}{\lambda}\left(x\mp\frac{\lambda_0}{4}\right).$$

thus

$$\frac{\partial i}{\partial x} = \mp a \frac{2\pi}{\lambda} \cos \frac{2\pi}{\lambda}\left(x \mp \frac{\lambda_0}{4}\right) = -j \frac{2\pi c}{\lambda} C V.$$

Numerically,

$$V = \frac{a}{cC} \cos \frac{2\pi}{\lambda}\left(x \mp \frac{\lambda_0}{4}\right).$$

The greatest value of V is equal to

$$(V)_{max} = \frac{a}{cC} \text{ volts.}$$

a is the maximum antenna current in amperes at a current loop and equals

$$\sqrt{2}\sqrt{\frac{\textit{Antenna Power in Watts}}{\textit{Total Antenna Resistance in Ohms}}},$$

where the total antenna resistance is referred to a current loop. The value of C is to be expressed in farad per cm. and c equals the velocity of light, that is, 3×10^{10}.

SUMMARY: The operation at the harmonics of the grounded antenna and of an ungrounded antenna at any distance above ground has been considered as far as current, voltage and power distribution, electromagnetic field and radiation resistance are concerned. The antenna is always assumed to be a straight vertical wire and unloaded. The ground is supposed to be a perfect conductor.

A METHOD FOR MAXIMIZATION IN CIRCUIT CALCULATION*

By

Walter van B. Roberts

(Radio Corporation of America, New York)

As an example of a problem involving a maximization, consider the circuit of Figure 1, where it is desired to determine what value of coupling makes the secondary current greatest. From the circuit equations the secondary current is readily found to be:

$$i_2 = -\mu\, e\, Z_c \frac{Z_m}{[Z_o Z_1 (R+Z_c) + Z_o Z_c R] - (R+Z_c) Z_m^2}. \qquad (1)$$

Now the straightforward method for finding the value of Z_m that makes i_2 a maximum is to reduce this expression for i_2 to its absolute value (by replacing Z_1 by $r_1+j\,x_1$, Z_o by $r_2+j\,x_2$, Z_c by

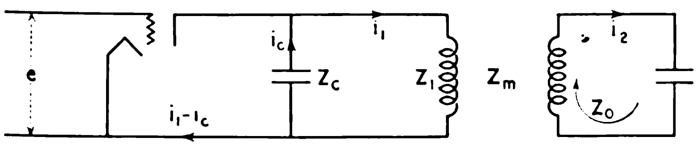

Figure 1—Internal Plate-Filament Resistance of Tube = R. Amplification Constant of Tube = μ. Z_o is Total Impedance Measured Around Secondary Circuit

$-j\,x_c$, and Z_m by $j\,x_m$), differentiate the absolute value with respect to X_m, set the derivative equal to zero, and solve for X_m. This is an extremely tedious process and leads to the result:

$$x_m^4 = (r_2^2 + x_2^2)\left[(r_1^2 + x_1^2) + \frac{R^2 x_c^2}{R^2 + x_c^2}\left(1 - 2\frac{x_1}{x_c} + 2\frac{r_1}{R}\right)\right], \qquad (2)$$

which result conveys little physical significance.

A much easier and more useful solution of the problem is, however, possible, based upon the following considerations: Let $f\,(Z)$ be any analytic function (and no other kind of function will be encountered in ordinary circuit theory) of the complex

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... e of Z is varied in some definite manner, ... complex plane will be some sort of curve. ... tion of such a curve, including a maximum ... At this maximum point it is obvious that a ... in the value of Z will move the point repre ... a direction perpendicular to the vector from the ... int of maximum absolute value. Now the change

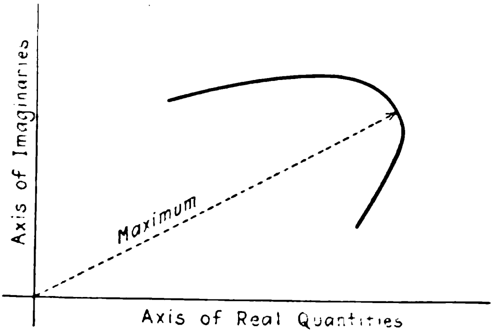

FIGURE 2

in $f(Z)$, due to a small change dZ in Z is $f^1(Z)\,dZ$, where $f^1(Z)$ is the function of Z obtained by differentiating $f(Z)$ with respect to the letter Z according to the ordinary rules of differential calculus. Hence, considering all these complex quantities and functions as vectors, the condition for maximum or minimum absolute value of $f(Z)$ is simply that the vector $f^1(Z)\,dZ$ must be perpendicular to the vector $f(Z)$.

Two special cases of this general condition are all that are usually required, for in circuit problems dZ is usually either a pure real quantity (such as a change in resistance of a circuit element) or a pure imaginary (such as a change in reactance of an element). In these cases we have the special conditions:

$f^1(Z)$ must be perpendicular to $f(Z)$ if dZ is real, (3)

$f^1(Z)$ must be parallel to $f(Z)$ if dZ if imaginary. (4)

which may be expressed in the more useful form:

The real part of $\dfrac{f(Z)}{f^1(Z)}$ must be zero if dZ is real. (5)

The imaginary part of $\dfrac{f(Z)}{f^1(Z)}$ must be zero if dZ is imaginary. (6)

Now going back to the problem of Figure 1, i_2 is seen to be of the form

$$i_2 = \frac{Z_m}{A - B Z_m^2}, \tag{7}$$

where A and B are complex constants. In Figure 1, Z_m is a pure reactance, so $d\,Z_m$ is imaginary, and condition (6) is applicable. That is, the imaginary part of $\dfrac{i_2}{\dfrac{d\,i_2}{d\,Z_m}}$ must be zero, or, imaginary part of $\dfrac{\dfrac{Z_m}{A - B Z_m^2}}{\dfrac{A + B Z_m^2}{(A - B Z_m^2)^2}}$ must be zero.

Simplifying, we have: Imaginary part of $\dfrac{A - B Z_m^2}{A + B Z_m^2} Z_m$ must be zero. To find out what value of Z_m satisfies this condition, replace A by $a + j\alpha$ and B by $b + j\,\beta$ and Z_m by $j\,x_m$. Then equate the imaginary part of the resulting expression to zero and it is readily found that $x_m^4 = \dfrac{|A|^2}{|B|^2}$.

Replacing $\dfrac{|A|}{|B|}$ by the proper quantities for this particular problem as given by equation 1, the solution becomes:

$$|Z_m^2| = |Z_o| \times \left| Z_1 + \frac{R\,Z_c}{R + Z_c} \right| \tag{8}$$

This solution is exactly the same as given by equation (2), as can be proved by reducing the indicated absolute values to an expression in terms of the quantities used in equation (2). This solution, however, gives a much simpler physical picture of conditions than equation (2). The last term is obviously the impedance of a circuit consisting of Z_1, connected in series with the combination of R and Z_c in parallel. (Let this be called for the moment the generator circuit.) And $\left|\dfrac{Z_m^2}{Z_o}\right|$ is immediately recognized as the impedance introduced into the "generator circuit" by the presence of the secondary. (Call this the load impedance.) Then the equation simply states that for maximum power in the load, the load impedance should be equal to the impedance of the "generator circuit" in absolute value. This is a very familiar type of statement.

Another Example of the Use of the Method

Figure 3 shows a common method for coupling an antenna to a tuned circuit. If a signal voltage e acts in the antenna

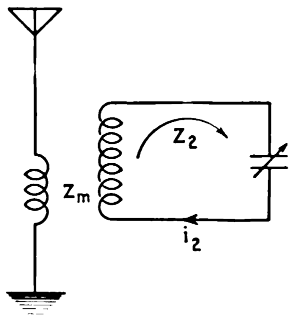

Figure 3—Impedance of Antenna Circuit $=Z$. Total Impedance Measured Around Secondary Circuit Above $=Z_2$. Mutual Impedance Between Circuits $=Z_m$

circuit, the secondary current is easily calculated:

$$i_2 = -e \frac{Z_m}{Z_1 Z_2 - Z_m^2}. \tag{9}$$

Suppose it is required to calculate what adjustment of the tuning condenser must be made to give maximum secondary current. Z_2 is the element that is to be varied, and although Z_2 is not pure imaginary, $d\,Z_2$ is pure imaginary because it is merely the reactance change due to varying the capacity. Therefore, to find what value of Z_2 makes i_2 maximum, apply condition (6). $\dfrac{d\,i_2}{d\,Z_2} = \dfrac{e\,Z_m Z_1}{(Z_1 Z_2 - Z_m^2)^2}$, so the condition is: Imaginary

part of $\dfrac{\dfrac{-e\,Z_m}{Z_1 Z_2 - Z_m^2}}{\dfrac{e\,Z_m Z_1}{(Z_1 Z_2 - Z_m^2)^2}}$ must be zero.

Simplifying, this becomes, imaginary part of $\left(Z_2 - \dfrac{Z_m^2}{Z_1}\right) = 0$ (10)

The nature of this result is evident, for the imaginary part of Z_2 is the reactance of the secondary circuit, while the imaginary part of $-\dfrac{Z_m^2}{Z_1}$ is the reactance introduced into the secondary by the primary. Thus the secondary condenser must be ad-

justed just enough "off tune" to offset the reactance introduced by the primary. It is easy to see that the larger Z_1 or the smaller Z_m, the less the condenser will be thrown "off tune." Also, if the primary coil is too small to resonate with the antenna capacity, Z_1 has a condenser or negative reactance component, and the reactance introduced into the secondary will be positive, so that the tuning condenser will have to be reduced in capacity from its normal value to compensate. On the other hand if the antenna inductance is larger than the value required for resonance with the antenna capacity, all the statements just made are reversed. Intermediate between the two conditions a large resistance is introduced into the secondary and no distinct maximum is obtained by varying the condenser. To minimize these peculiar effects upon the secondary tuning, the antenna circuit reactance is usually kept at a large negative value by means of a series condenser, or using few enough turns for each wavelength being received to assure that the antenna circuit reactance remains negative and of large value. As far as the equations go, it should also be possible to minimize the effect upon the secondary tuning by using a primary of inductance so large as to assure a large positive reactance in the antenna circuit.

It should be noted that (10) is an equation in the imaginary parts of the expression, so that the expression cannot be arranged to read $Z_1 - \frac{Z_m^2}{Z_2} = 0$, or even the imaginary part of it equal zero. Thus while the secondary circuit is tuned in the sense that the total effective reactance is made zero for maximum current, it is not true that the effective reactance of the antenna circuit is zero at the same time. This fact gives a certain amount of justification for calling this type of antenna circuit "untuned," though not for calling it "aperiodic."

SUMMARY: Having found the expression for a current (or voltage or power, etc.) in terms of complex quantities representing the constants of a circuit, it is often desired to determine what value of some one of these complexes makes the absolute magnitude of the current (or voltage, etc.) a maximum or a minimum. Rather than reduce the expression to its absolute value first, and then maximize in the usual way, it is often much less tedious to differentiate the expression while in the complex form. The condition that the absolute value is an extremum is then not that the derivative is equal to zero, but that the derivative multiplied by a small increment of the independent variable gives to the dependent variable an increment which is at right angles to the vector representing the dependent variable itself The condition of maximum obtained by this method is often in a form that is more compact and that has obvious physical significance. Two examples of the use of the method are given.

ON THE ORIGIN OF THE SUPER-HETERODYNE METHOD*

By

Walter Schottky

Mr. E. H. Armstrong recently explained in this Journal[1] that the idea of the receiving method named by him "Super-Heterodyne Reception" first occurred to him as a solution of the requirements of a war problem, and that in the course of further investigations, and due to various suggestions for improvements, this idea resulted in the excellent broadcasting receiving set that we admire so much to-day. As interchange of views and, consequently, uniformity of scientific and technical development have now apparently been re-established to a large extent between the enemy countries, you will no doubt allow me to give a short outline of how and when the corresponding idea took shape in Germany.

It was a special and relatively unimportant war problem, namely wireless remote control, which claimed the collaboration of the Siemens Laboratory—whose experiments were in part managed by me—in the course of 1917[2].

As in the case of the problem mentioned by Mr. Armstrong, discrimination against waves of other frequencies and atmospheric disturbances was the dominant aim, and thus led to theoretical investigations relating to the selectivity problem of radio reception in general. The most obvious suggestion of improvement consisted in modulating the transmitted high frequency by means of a lower one, and in providing a correspondingly double-tuned receiving set,—a suggestion which, as we now know, was the chief claim of Lucien Lévy's patent application, filed in the summer of 1917[3]. An exhaustive investigation which I made in December 1917, of the advantages that

*Received by the Editor, April 20, 1926.

[1] The Super-Heterodyne, Its Origin, Development and Some Recent Improvements, October, 1924.

[2] The Zentrallaboratorium of the Wernerwerk, known at that time as "Schwachstromkabel (K—) Laboratorium."

[3] English Pat. 143583 dated August 4, 1917. See also B. F. Meissner, Radio Dynamics 145-149, New York, 1916.

might be gained by this method as applied to transmitting and receiving sets showed, however, that these would not altogether fulfil our immediate expectations. Under the most varying conditions possible, I compared the effects which an impulse (*i.e.* a sudden alteration of the electric field intensity) or a non-modulated radio frequency signal would produce in the terminal set with the effect of the signal to which the receiving set was intended to respond; and I established the fact that insensitivity to impulse disturbances is, to a large extent, *only dependent on the ratio of the period*[4] *required for the terminal signal, to the period of the (most rapid) radio frequency cycle employed.* Only in the case of interference due to non-modulated radio frequency signals lasting longer than about one-third of the audio frequency cycle, did a correspondingly reduced sensitivity result compared with a simple receiving *circuit* tuned to this interfering frequency. Furthermore, the ratio of interference sensitivity to signal sensitivity was chosen to be dependent on whether the rectification of the mean frequency followed a linear law or, (as in the case of weak signals in ordinary detectors and rectifiers) a square law; it was shown that the square law rectifying action prejudicially affected the ratio of interference sensitivity to signal sensitivity. For this reason, and on account of the well-known loss in amplification which cannot be avoided with weak signals under square-law rectification, I considered the possibility of amplifying, by means of a non-selective radio frequency amplifier, the two adjacent frequencies γ_1 and γ_2 contained in the modulated carrier wave, to such an extent before their passage through the first rectifier, that the rectifying action would become approximately linear. But here I encountered a problem, the general importance and difficulties of which were already familiar to me, and which I had at first hoped to solve by the construction of special amplifying valves having large electronic currents and small internal resistance[5]. My acquaintance with the idea of inaudibly-modulated carrier frequency presented me (at the end of February and beginning of March) with a new solution, viz: that the incoming high frequency (at frequencies γ_1 and γ_2 or, in case of non-modulated high frequency transmission, at frequency γ) could be converted linearly like ordinary heterodyne reception—into a lower fre-

[4] Where mechanical relays are operated, the period of the terminal signal may be the natural oscillation of the armature; in the case of telephonic signals the cycle of the highest frequency that can be transmitted.

[5] D. R. P. 366829, filed November 11, 1917.

quency wave which could be easily amplified, by causing the first receiver valve to oscillate at a frequency which would give inaudible beats when receiving the incoming high frequency. In order to obtain the linear conversion of the wave, the amplitude of this auxiliary oscillation should be dimensioned in such a manner that it entirely *controlled the super-heterodyne valve over about one-half its characteristic.*

It was by no means difficult to recognise the importance of this method, which actually represents the super-heterodyne principle, for all purposes of radio reception. In fact, the following entry was made by me in the journal of the K = Laboratorium for the period February 25 to March 16, 1918:

"*A Frequency Transformation for Radio Reception*

"As the amplification of very short waves in many "cases involves a large consumption of energy in the "amplifier valves employed, it is of advantage to be able "to convert short waves at their reception, without any "loss of energy, into longer, similarly inaudible waves and "then to amplify these only. This is accomplished by "heterodyning another frequency differing by about "10 % so that the beat-wave again becomes high frequen-"cy, but longer. Of special importance for radio telephony "in which ordinary heterodyning is not possible."

The German patent for this method was filed on the 18th June, 1918[6]; since I could not myself draw it up nor pursue the matter further, it did not, unfortunately, assume the form I should have wished. Nevertheless, it emphasizes the essential features of the super-heterodyne method and, thanks to the Nolan Act, patents have been granted in America and England, so that according to the present state of patent law in these countries as well as in Germany, the manufacture of at least such heterodyne sets as permit the *amplification* of the transformed (inaudible) high frequency, is involved in the possession or right of utilization of this patent.

I should like to conclude this little historical note by referring to some still earlier publications and patent applications in our field[7], which are of historical importance in relation to the super-heterodyne idea, but were, probably, as unknown to Mr. Armstrong as to me. The idea of employing the advantages of heterodyne reception for radio telephony also, by selecting an

[6] D. R. P. 368937; English Pat. 135177, appl. 1502063. The first patent E. H. Armstrong is dated 30th December, 1918.

[7] See also the report of J. H. More, Electrician, 1925, p. 121.

inaudibly high beat frequency, was probably published originally in 1913 by Mr. Hogan in the course of a discussion[8]. The idea of producing a beat frequency by means of a local source of oscillation, which was not intended to make the signals audible, but expressly to provide for another tuning and thereby increased selectivity, has been patented by Graf Arco and A. Meissner[9], and by H. J. Round[10]; Round's application also lays stress on providing inaudible beat frequencies, but actually offers no good selectivity against interference owing to the inherent necessary detuning of the aerial. Finally, the aforementioned patent of Lucien Lévy[11] is of fundamental importance to the whole field; he must be considered, at least from the point of view of patent law, as the true originator of the super-heterodyne method, since the super-imposition of an adjacent frequency, an intermediate circuit tuned to inaudible frequencies, and a further rectification in order to convert into the desired signal, are described explicitly in his application (as one of several constructions). In regard to earlier existent publication, there may be a doubt as to whether the information would have brought about the desired technical progress we owe to the super-heterodyne method, as conceived by Mr. Armstrong and also described in the German application. After all, the actual aim of the high-frequency transformation or super-heterodyning principle consists in providing a suitable and relatively convenient radio frequency amplifier for short waves, whereas the selectivity effects that Lévy solely had in view are less important, according to the above considerations, and might be obtained as well by the use of a slightly attenuated or reaction-coupled radio frequency syntonizing circuit. The drawings of this application also leave it doubtful whether the elimination of the square-law rectifying action, which is so essential for the commercial use of the apparatus, would have been obtained by means of experimental sets constructed on the principle indicated in the application.

The "word" seems, at any rate, to have been far less important in this field than the "deed," and there appears to be no doubt that it is Mr. Armstrong and his collaborators to whom we owe the deed, which has made the super-heterodyne method such as invaluable instrumentality in radio engineering.

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[8] Hogan, PROCEEDINGS OF THE INSITUTE OF RADIO ENGINEERS, 1,97 (1913).

[9] English Pat. 252, 1914, filed January 5, 1914 and D. R. P. 300896, January, 15, 1917.

[10] English Pat. 27480, 1913, filed November 11, 1913.

[11] English Pat. 143583, date of appl. April 8, 1917.

DISCUSSION ON PORTABLE RECEIVING SETS FOR MEASURING FIELD STRENGTHS AT BROADCASTING FREQUENCIES, BY AXEL G. JENSEN*

By
G. D. Gillett
(Department of Development and Research, American Telephone and Telegraph Co.)

Mr. Jensen has so fully covered the technical features of these new measuring sets that I think it would be impossible for me to add anything of importance to that phase of the subject except to emphasize, as Mr. Jensen failed to do through modesty, just how great an advancement the replacing of the method of balancing voltages impressed on the grid of the first detector with one involving the balancing of the voltages induced in the loop represents in the art of measuring field strengths at broadcast frequencies. Advancement both in the sustained accuracies obtainable in field work and even more in their ruggedness and convenience in the field. We have found that on the average we can accomplish nearly twice as much work with these new sets as we could with the old type which they replace. Also, it may be of interest to you to see how these sets are being used in the field in actual field strength measuring work, and to review both the uses to which they have been put as well as the ones to which they may be put and for which they are peculiarly well adapted.

Originally our field work was done with sets which we carried on the back seat of an ordinary touring car, relying on the cushion effect of the seats themselves to protect them from severe road shock. This involved lifting them up on a small platform every time a measurement was to be made, and attempts were made to develop a spring mounting which would satisfactorily protect them from road shock and at the same time carry them in position ready for instant use. Figure 1 will show our solution of this problem with the sets closed and the loop mounted on the running board of the car ready to go.

*Received by the Editor, May 19, 1926.

The mounting for the sets consists of a heavy wooden box supported on an equally heavy angle iron frame, this box being lined on the bottom, sides, and back with heavy automobile type cushions, and the sets are carried in a felt lined light wooden frame upon these cushions. Since it is necessary to reach the front and top of the sets during operation, it was impossible to surround them entirely by cushions, and instead the sets were clamped into the light frame, and this box frame is held against

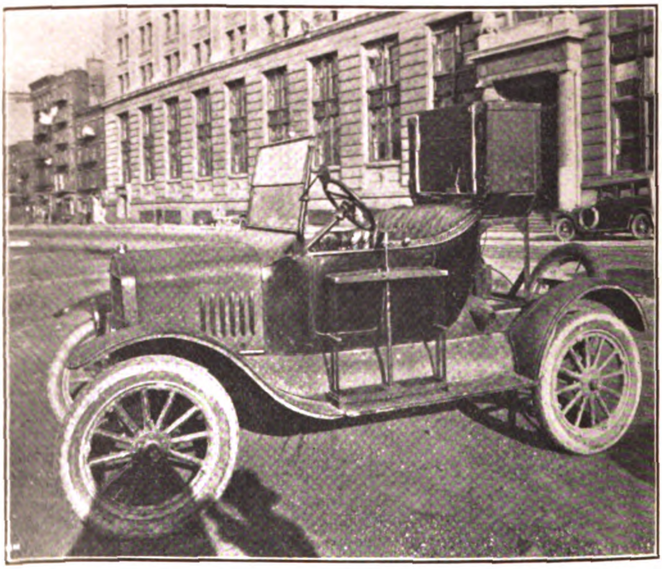

FIGURE 1

the cushions by four heavy steel coil springs located at the bottom and top rear corners of the mounting. This cushion mounting has been very successful in protecting the sets from injury by road shock as well as convenient in operation. We also thought it looked quite handsome until the proprietor of an electrical shop where we stopped to get some batteries asked us, "What kind of a washing machine is that?"

Figure 2 shows the sets with the loop inserted in its socket and the set in operation. When a measurement is to be made, all that is necessary is for the driver to remove the loop from the spring clips in which it is held, insert it in the socket on the top of the set, and plug in his receivers. The batteries are turned on by the insertion of the receiver plug. The condenser dials are fitted with clamps so that the set remains in tune. This makes

it a very convenient arrangement and we have found it possible to make as many as nine separate measurements in an hour at points spaced one mile apart.

FIGURE 2

Examples of the first work done in the field with measuring sets involved a small survey around New York City and another around Washington, D. C. The results of these surveys are shown in Figures 3 and 4. The form of the contour lines show clearly for the first time the very wide departure of field strength distribution from the ideal, especially in congested areas filled with absorbing metallic structures. In the case of New York City, the shadow cast by the 42nd Street district north over the Central Park area, and another cast by the downtown skyscrapers over Governors Island and lower Brooklyn are clearly shown by the marked dents in the contour lines. These data were included in a paper by Mr. Bown and myself presented before this Institute in 1924.

Shortly after these surveys were made, field strength measuring sets of the early type were used to make a quantitative comparison of the transmission from a transmitting station located at 24 Walker Street and a transmitting station located only one mile away at 463 West Street, both in New York City. The results of these comparative measurements rather surprised us

by showing a difference, at certain points in the lower tip of Connecticut, of over 100 to 1 in power efficiency of transmission between these two stations, only a mile apart.

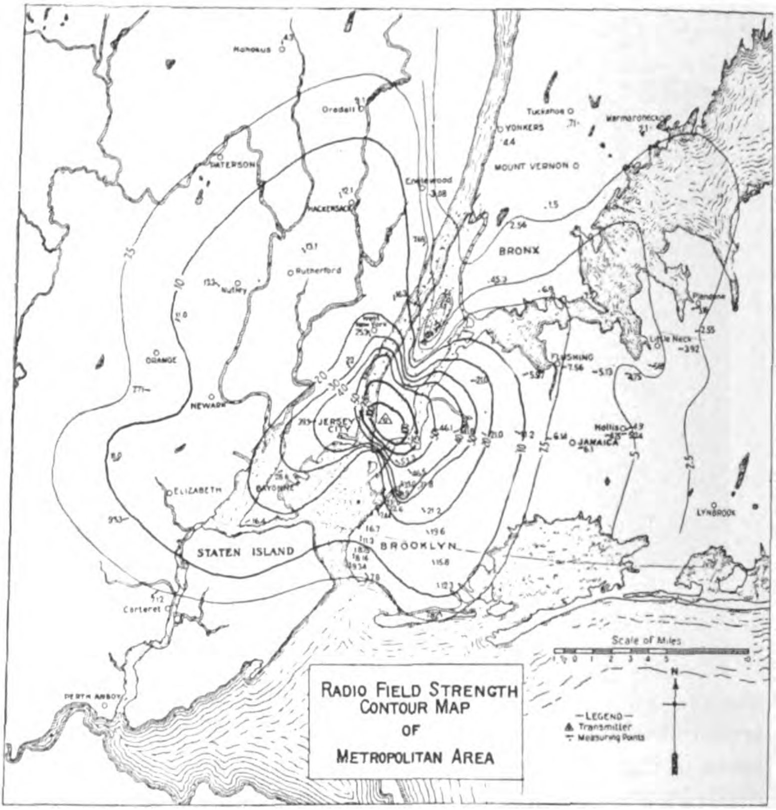

FIGURE 3—Radio Field Strength Contour Map of Metropolitan Area (Field Strenghts in Millivolts per Meter)

In an attempt to get some explanation of the possible causes of such a condition, a complete detailed survey was made of Westchester County and the lower tip of Connecticut, which resulted in the field strength contour map shown in Figure 5. The contours on this map show that there is a series of long nearly parallel hills and valleys of field strength. There has occurred to us, as an explanation, that this hitherto uncharted form of field strength distribution is a gigantic wave interference pattern. This interference pattern probably results from the extremely heavy absorption of the high building area around the 42nd Street district with its resulting shadow and the feeding in

from each side of this shadow as the waves progress out over Westchester.

This same shadow effect has been definitely located by means of these measuring sets in connection with the use of a portable transmitter, shooting at this 42nd Street district from different directions. In Figure 6 is shown the location of the portable transmitter at these different points with a large enough fragment of the resulting contour map to show the shadowing effect. The intersections of the lines drawn from the shadows to the transmitter fall at approximately 38th Street in the vicinity of

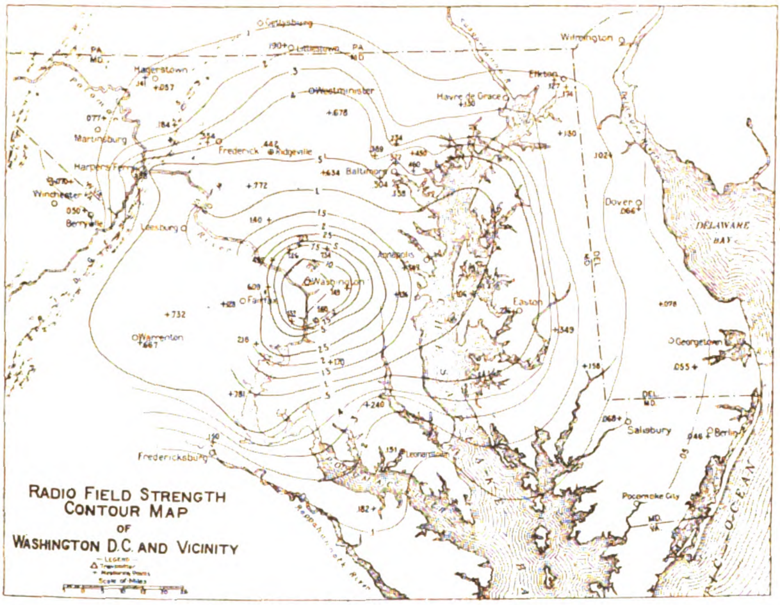

FIGURE 4—Radio Field Strength Contour Map of Washington, District of Columbia and vicinity

Sixth Avenue, definitely locating the center of gravity at least of the area of abnormally heavy absorption. The interference pattern given above and our conclusions as to the nature of the effect of the building area on the interference pattern were first described in a paper presented before this Institute last fall, "Some Studies in Radio Broadcast Transmission," by Messrs. Bown, Martin and Potter.

Finally, I should like to point out that such sets as these are the only means available at the present time for making accurate and complete field strength surveys of a broadcasting station. By the use of a portable transmitter, in connection with surveys

made in this way, it is possible to evaluate accurately in advance of any costly construction, the relative merits of different sites for the location of a new broadcasting station, and thus avoid the chance of unsatisfactory performance which has been experienced by so many stations located in dense metropolitan areas.

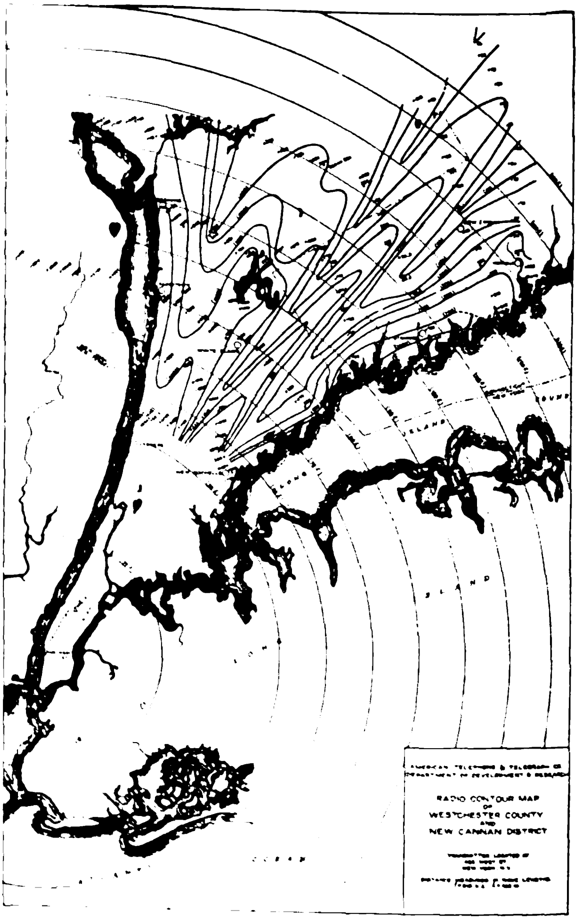

FIGURE 5 Radio Contour Map Showing Wave Interference Pattern

These sets also are peculiarly well adapted for the location of noise or interference of any sort. Heretofore, it was necessary to have a carrier from some transmitting station in order to bring the noise or interference in as sideband and thus raise it to an audible level in the receiver comparable to ordinary receiving conditions. But due to the directional characteristic of the carrier it was impossible to use a directional receiver to determine

the bearing of the source of the noise. With these sets it is possible, from the local signal input oscillator, to supply a carrier of any known or desired value and frequency without a directional characteristic, and to use this carrier to sensitize the receiver so that the loop's directional characteristic may be used to locate the bearing of the incoming noise and thus to trace down the source of noise.

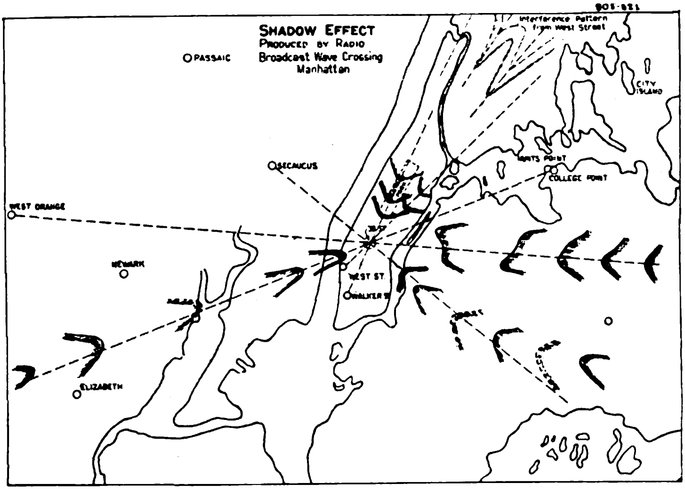

FIGURE 6—Map Showing Location of Radio Obstruction on Manhattan Island as Determined by the Intersection of Lines Between Various Transmitting Points and Their Corresponding Shadows

In conclusion, perhaps the best indication of the value of these sets in research work is given by the fact that we have thought it worth while to carry sets of these types over 15,000 miles in the last three years in the making of field measurements and have made a total of about three thousand separate measurements.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY

Issued May 11, 1926—June 30, 1926

By

JOHN B. BRADY

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,584,015—G. S. CORNISH, of Madisonville, Ohio. Filed November 22, 1924, issued May 11, 1926. Assigned to the Cincinnati, Patent Engineering Company.

CONDENSER AND LEAD FOR RADIO CIRCUITS, where a pair of condenser plates are disposed at right angles to each other on an insulated base and their terminals shunted through a high resistance coating.

1,548,220—H. FARKOUGH, of Brooklyn, N. Y. Filed May 21, 1923, issued May 11, 1926.

PORTABLE RADIO RECEIVING SET, in the form of a suit case having extensible feet thereon by which the suit case may be set up at an angle for convenience in operation.

1,584,490—A. H. TAYLOR, of Washington, D. C. Filed November 30, 1925, issued May 11, 1926. Assigned to Wired Radio, Incorporated, of New York City.

THREE-PHASE OSCILLATOR, where three single phase oscillation generator circuits are connected in Y and the oscillation circuits controlled by a piego-electric crystal for maintaining the several currents in proper phase displacement.

1,584,551—E. W. KELLOGG, of Schenectady, N. Y. Filed October 29, 1924, issued May 11, 1926. Assigned to General Electric Company.

RADIO RECEIVING SYSTEM, in which a pair of directionally extending horizontal conductors are provided with means for producing reflection of different phases in the two conductors for the selective reception of signals.

1,584,893—F. A. RAFFERTY, of Villanova, Pennsylvania. Filed June 21, 1923, issued May 18, 1926.

CONSTANT INDICATOR FOR VIBRATORY CIRCUITS, consisting of a meter in which the frequency of the electromagnetic wave may be read directly in kilocycles and cycles or in meters and the product of inductance and capacities in micro-henries and micro-farads may be read directly.

1,585,244—W. H. HOFFMAN, of Madison, Wisconsin. Filed February 17, 1925, issued May 18, 1926. Assigned to C. P. Burgess Laboratories.

SHORT WAVE LENGTH TRANSMITTER, in which an electron tube circuit is stabilized for operation by means of a bridge circuit which maintains the system in a condition of oscillation at constant frequency.

1,585,431—W. O. SNELLING, Allentown, Pennsylvania. Filed September 24, 1923, issued May 18, 1926.

CURRENT-RECTIFYING DEVICE, consisting of a metallic sulphide prepared in the presence of a reagent comprising sulphide dioxide and carbon bisulphide.

1,585,445 J C WARNER, Schenectady, N. Y. Filed February 29, 1924, issued May 18, 1926. Assigned to General Electric Company.

ELECTRON DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME, in which a pair of grid electrodes are provided, interposed between the cathode and anode and the flow of current between the cathode and anode controlled by the conjoint action of two grids.

1,584,923 O. GRUENBERGER, Wauwatosa, Wisconsin. Filed December 29, 1922, issued May 18, 1926.

ELECTRICAL CONDENSER, in which a pair of plate members is provided and the mutual exposure controlled by flexing or rolling of one plate upon another.

1,586,060—R. BAINTON, Greeley, Colorado. Filed July 18, 1922, issued May 25, 1926.

MEANS FOR GUARDING AGAINST THE UNAUTHORIZED RECEIVING OF RADIO COMMUNICATIONS, employing a cam operated mechanism at both the transmitting and receiving stations for varying the operating wave length in accordance with a definite law for the purpose of secrecy.

1,586,144—H. J. J. M. de R. de Bellescize, Toulon, France. Filed August 18, 1919, issued May 25, 1926.

STATION FOR DUPLEX RADIO TELEGRAPHY, employing a loop antenna perpendicular to the direction of the transmitter with a directional collector coupled to the loop for compensating for any unsymmetrical relations between the loop and the conductors of the transmitter having oscillations induced therein.

1,586,162—J. C. R. PALMER, New Rochelle, N. Y. Filed March 29, 1923, issued May 25, 1926. Assigned to Western Electric Company, Incorporated.

ELECTRON DISCHARGE DEVICE, where the control electrode consists of a wire helix surrounding the cathode with the control circuit connected across the wire helix.

1,585,650 G. H. CLARK, Brooklyn, N. Y. Filed June 27, 1922, issued May 25, 1926. Assigned to Radio Corporation of America.

ARC GENERATOR, wherein oscillations are maintained at constant frequency by a plurality of windings around the arc field.

1,585,766 L. W. CHUBB, Edgewood Park, Pennsylvania. Filed May 15, 1917, issued May 25, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

THERMIONIC CONVERTER, embodying two electrodes having different electron emissivity when equally heated and arranged for the passage of uni-directional current between the electrodes.

1,585,878—H. O. RUGH, Chicago, Illinois. Filed November 16, 1922, issued May 25, 1926.

THERMIONIC VALVE for connection in an incandescent lamp socket, serving as a complete radio receiving set for the external connection of a headset and tuning circuit therewith. The valve functions as a rectifier of incoming signaling energy.

1,586,199 G. HOLST, E. OOSTERHUIS and J. BRUIJNES, of Eindhoven, Netherlands. Assigned to Naamlooze Vennootschap Philips' Gloeilampen Fabrieken.

ELECTRICAL DISCHARGE DEVICE for the purpose of rectification where two electrodes are provided with a shield of insulating material interposed between the electrodes.

1,586,419—W. S. FREESLAND, of Norfolk, Virginia. Filed October 2, 1922, issued May 25, 1926.

MULTICONTACT CRYSTAL DETECTOR, where a switching arrangement is provided for selecting a plurality of sensitive points of a crystal and effectively including such points in a circuit.

1,586,498—S. K. WILSON, of Philadelphia, Pennsylvania. Filed January 26, 1925, issued May 25, 1926.

CONDENSER for variable adjustment in which a pair of cylinders are provided axially movable one within the other.

1,586,524—R. A. HEISING, Millburn, N. J. Original filed December 29, 1916; renewed April 28, 1924, issued June 1, 1926. Assigned to Western Electric Company.

CONSTANT FREQUENCY SYSTEM, where an arc excited oscillating circuit is controlled in stable condition independent of variations which occur in the resistance of the load circuit.

1,586,558—J. E. HARRIS, Newark, N. J. Filed November 20, 1922, issued June 1, 1926. Assigned to Western Electric Company.

MANUFACTURE OF ELECTRON DISCHARGE DEVICES, where the electron tubes are evacuated while establishing a space discharge between the electrodes in an atmosphere of carbon monoxide.

1,586,580—J. C. SCHELLENG, Millburn, N. J. Filed August 20, 1925, issued June 1, 1926. Assigned to Western Electric Company.

OSCILLATING SYSTEM, where the frequency of the system may be changed by varying the inductance and capacity circuits simultaneously by means of a mechanical switching system.

1,586,653—F. CONRAD, Pittsburgh, Pennsylvania. Filed March 10, 1922, issued June 1, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

RADIO TRANSMISSION SYSTEM, where a plurality of non-parallel antennae are provided tuned to the same frequency and a connection between a source of oscillations with one of the antenna circuits, the other antenna circuits being connected between points of like potential and the oscillation circuit for oscillating in unison.

1,586,657—S. DAVIDSE, Wheeling, West Virginia. Filed May 17, 1923, issued June 1, 1926.

INDUCTIVE LOOP ANTENNA, where a plurality of separate loop frames are variably positioned upon a support for mutual adjustment thereon.

1,586,672—E. L. HACKETT, Wyoming, N. J. Filed September 5, 1922, issued June 1, 1926. Assigned to M. H. Avram & Company, Incorporated.

CRYSTAL DETECTOR, having a micrometer adjustment for the cat whisker with respect to the crystal.

1,586,755—J. F. LINDBERG, Chicago, Illinois. Filed September 25, 1922, issued June 1, 1926. Assigned to Reliance Die & Stamping Company.

INDUCTANCE APPARATUS, comprising an inductance coil concentrically mounted around a condenser with a mechanical device for changing the angular position of the inductance coil with respect to the condenser.

1,586,828—A. H. MILLER, Detroit, Michigan. Filed November 26, 1923, issued June 1, 1926.

RADIO DETECTOR, where a crystal is embedded in a low fusing alloy and mounted within a tubular container with a contact device permanently secured upon a sensitive point of the detector.

1,586,895—J. J. GILBERT, Port Washington, N. Y. Filed May 15, 1922, issued June 1, 1926. Assigned to Western Electric Company.

SUBMARINE CABLE SIGNALING for two-way signaling between two stations where a mechanical arrangement is provided for permitting simultaneous transmission from both stations and reception at both stations over equal periods of time.

1,587,095—B. R. WEBSTER, Chicago, Ill. Filed April 28, 1924, issued June 1925. Assigned to Reliance Die & Stamping Company.

ELECTRICAL CONDENSER, having rotor and stator plates with the movable shaft reduced in the form of a quill and journal in the condenser frame for accurate adjustment therein.

1,587,096—A. E. WHEELER, Logansport, Indiana. Filed June 30, 1925, issued June 1, 1926.

COMBINED RADIO LOUD SPEAKER AND LAMP, wherein an acoustic horn is combined with a support for a lamp.

1,587,156—W. G. HOUSKEEPER, New York City. Filed November 26, 1920, issued June 1, 1926. Assigned to Western Electric Company.

VACUUM INSULATOR for the lead in of conductors into a high power vacuum tube where inner and outer axial cylinders of insulating material form a passage for the lead in through the wall of the vacuum tube.

1,587,168—M. MATHIESEN, of Chicago, Illinois. Filed April 13, 1925, issued June 1, 1926. Assigned to Mathiesen-Sandberg Company.

LOOP AERIAL, designed for portable erection where the frame members are hinged together.

1,587,389—O. G. LISSEN, Jersey City, N. J. Filed March 13, 1924, issued June 1, 1926.

CONDENSER of multiple construction with a single shaft for controlling the condenser simultaneously and a friction device for independently controlling the movement of the condensers.

1,587,210—R. V. L. HARTLEY, East Orange, N. J. Filed February 3, 1919, issued June 8, 1926. Assigned to Western Electric Company.

NONRESONANT SYSTEM, including a plurality of electron tube repeaters with circuits for driving current through each repeater and an electromagnetic control operated by the flow of current through each repeater tending to reduce the simultaneously existing current through the other repeater.

1,587,696—A. J. CARTER, Chicago, Illinois. Filed March 14, 1924, issued June 8, 1926. Assigned to Carter Radio Company.

ELECTROSTATIC CONDENSER of the stack type where U-shaped terminals are provided for subjecting the stack to pressure and establishing connection with opposite sides of the condenser.

1,587,786—J. MASSOLLE, HANS VOGT and DR. JOSEF ENGL, of Grunewald, Berlin and Grunewald, Germany, respectively. Filed April 4, 1921, issued June 8, 1926. Assigned to Tri-Ergon Limited of Zurich, Switzerland.

ELECTRON TUBE having anode screening means with a connection between the source and the anode screening means.

1,587,880—R. A. WEAGANT, New York, N. Y. Filed February 7, 1919, issued June 8, 1926. Assigned to Radio Corporation of America.

METHOD AND APPARATUS FOR RADIO SIGNALING, wherein a pair or horizontally extending antennas are arranged to be moved in a vertical or horizontal plane for securing the maximum response to signaling energy free of static disturbances.

1,587,595—F. LOWENSTEIN. Filed November 5, 1920, issued June 8, 1926. Assigned to Radio Patents Corporation.

TELEPHONY, wherein the efficiency of transmission and reception is considerably increased by suppressing at the transmitter the lower frequency notes which normally require considerably more power for transmission than the higher frequency notes and restoring the lower frequency notes at the receiver. The patent covers both the method of transmission and apparatus for effecting such transmission.

1,587,657—F. A. KOLSTER, of Burlingame, California. Filed December 5, 1921, issued June 8, 1926. Assigned to Federal Telegraph Company.

RADIO SIGNALING SYSTEM for signaling between one station and either of two others which are substantially in the same line and in the same direction with respect to the first station. Circuits are provided for the selective transmission and reception of the signaling energy in a definite prescribed path.

1,587,662—F. LOWENSTEIN. Filed November 29, 1918, issued June 8, 1926. Assigned to Radio Patents Corporation.

APPARATUS FOR GENERATING ALTERNATING CURRENT for radio transmission where a pair of parallel branch circuits each including an electron tube system are so connected with an antenna system as to conjointly deliver energy to the antenna system with a circuit for modulating the effects of transmitted energy.

1,587,924—H. J. ROUND and A. McLELLAN, of London and Swansea, England, respectively. Filed March 30, 1921, issued June 8, 1926. Assigned to Radio Corporation of America.

RADIO SIGNALING SYSTEM, where a circuit arrangement is provided for maintaining the tuning of an antenna constant under conditions of change in load.

1,587,932—G. D. BAGLEY, Flushing, N. Y. Filed December 4, 1922, issued June 8, 1926. Assigned to Electro Metallurgical Company.

SPARK GAP APPARATUS, comprising separate intercommunicating electrode chambers containing hydrogen. Electrodes are arranged in the chamber and adjustable mercury pools provided for the other electrodes whereby discharge takes place in hydrogen.

1,587,942—W. DUBILIER, of New York, N. Y. Filed March 7, 1919, issued June 8, 1926. Assigned to Dubilier Condenser & Radio Corporation.

CONDENSER STRUCTURE, wherein a stack is secured under pressure and a casing engaged over the stack and secured to an insulating block arranged adjacent one end of the stack.

1,588,047—M. Osnos, of Berlin, Germany. Filed February 12, 1923, issued June 8, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

CIRCUIT ARRANGEMENT FOR RADIO SIGNALING, including a source of high frequency energy with an oscillatory circuit connected therewith, the oscillatory circuit comprising inductance and capacity so adjusted as to resonate the transmitting frequency while bi-passing all the undesirable higher frequencies.

1,588,248—D. G. McCAA, Lancaster, Pennsylvania. Filed March 23, 1923, issued June 8, 1926. Assigned to The Electric Apparatus Company.

ANTISTATIC SYSTEM for radio receiving systems where a vibratory contact member is actuated at the receiver in step with received telegraphic signals for the reception of the signals independent of interference.

1,587,512—W. DORNIG, of Berlin-Steglitz, Germany. Filed February 2, 1921, issued June 8, 1926.

HIGH-FREQUENCY TRANSFORMER for radio transmission where the transformer circuit is coupled to an antenna system through an intermediate tuning circuit for controlling the effect of the high frequency energy thus developed upon the antenna.

1,588,074—C. D. WHITE, HARRY STEVENSON and DAVID H. MOSS, of New Jersey. Filed November 4, 1925, issued June 8, 1926. Assigned to Brandes Laboratories, Incorporated, of Newark, New Jersey.

AUDIO-FREQUENCY TRANSFORMER, where the windings are magnetically shielded by a pair of closure members which embrace opposite sides of a channel-shaped frame.

1,587,764—ROBERT D. DUNCAN, JR., of East Orange, New Jersey. Filed December 23, 1925, issued June 8, 1926. Assigned to Wired Radio Incorporated, of New York City.

WIRED RADIO TRANSMITTING SYSTEM, in which a plurality of transmitters may be arranged for impressing high-frequency oscillations on line wire circuits without interference between the several transmitting frequencies for the transmission of a plurality of programs over a line wire network to a multiplicity of subscribers.

1,588,545—W. H. Gerns, of East Orange, New Jersey. Filed November 28, 1925, issued June 15, 1926. Assigned to Brandes Laboratories, Incorporated, of Newark, New Jersey.

ELECTROMAGNETIC DRIVER, particularly adapted for a conical diaphragm sound reproducer, wherein an armature member is driven by a pair of electromagnetic systems positioned on opposite sides of the armature. The armature is constructed for the efficient reproduction of notes over the entire musical scale.

1,588,438—H. N. BLISS, Ithaca, New York. Filed November 4, 1924, issued June 15, 1926.

METHOD AND APPARATUS FOR SELECTIVE ELECTRICAL TUNING, in which a set of rotor plates may be variably interleaved with a set of stator plates and independent movement imparted to the stator plates for compensating for variations in the differences in the plurality of stages of amplification.

1,588,474—A. A. KENT, Ardmore, Pennsylvania. Filed June 6, 1925, issued June 15, 1926.

CONDENSER for panel mounting within a receiver where the stator elements are supported from a bracket engaging the panel and the rotor elements are journaled in a single bearing carried by the panel.

1,588,519—Q. A. BRACKETT, Springfield, Massachusetts. Filed September 29, 1921, issued June 15, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

GRID LEAK formed within an electron tube by means of an auxiliary cathode device which is arranged parallel to the normal cathode and maintained at electron emitting temperature for providing a leak path with respect to the grid electrode.

1,588,671—C. S. GERBER, Pittsburgh, Pennsylvania. Filed April 1, 1925, issued June 15, 1926.

ELECTRIC CONDENSER, in which a rotatable member carries a pair of shaped plates on opposite sides of a stationary plate for variation in capacity in accordance with a definite law.

1,588,813—W. SCHEPPMAN, Berlin, Germany. Filed August 31, 1921, issued June 15, 1926. Assigned to Lorenz Aktiengesellschaft.

OSCILLATION CIRCUIT for the production of sustained oscillations where an electron tube system has the constants proportioned for the generation of oscillations with a condenser in shunt with the grid and plate circuits for the sustaining of oscillations.

1,589,008—J. B. KIRBY, West Richfield, Ohio and H. S. SCOTT, Cleveland, Ohio. Filed August 5, 1925, issued June 15, 1926. Said Scott assignor to said Kirby.

RADIO CONDENSER, having an attachment consisting of a plate of insulating material adapted to be inserted to a variable extent between certain of the plates of the condenser for fixing the capacity of the condenser.

1,589,204—L. H. MILLER, Lakewood, Ohio, and M. W. SEVERANCE, Cleveland, Ohio. Filed December 14, 1922, issued June 15, 1926. Assigned one-third to Arthur H. Voigt.

VARIABLE CONDENSER for accurate adjustment of the capacity of an electrical circuit wherein a tubular member is rotated within a screw threaded cylinder and the gap therebetween filled with dielectric.

1,589,308—J. A. VICTOREEN, Cleveland, Ohio. Filed April 30, 1926, issued June 15, 1926.

RADIO-FREQUENCY APPARATUS, consisting of a combined transformer and variable condenser unit forming a coupling device for electron tube circuits.

1,589,344—M. K. AKERS, Troy, Ohio. Filed December 2, 1920, issued June 22, 1926. Assigned to Western Electric Company, Incorporated.

RADIO-SIGNALING SYSTEM, arranged for duplex operation where locally transmitted energy is prevented from interfering with reception by means of a balanced transformer associating the transmitting and receiving apparatus in conjugate relation with respect to a closed loop and open antenna.

1,589,483—G. H. PERRYMAN, New York City. Filed November 3, 1925, issued June 22, 1926. Assigned to Perryman Electric Company, Incorporated.

VACUUM TUBE having a brace member for the electrodes within the tube for strengthening the electrode support and preventing injury to the electrodes as a result of rough handling.

1,589,925—R. R. BATCHER, Jamaica, New York. Filed December 19, 1924, issued June 22, 1926. Assigned to A. H. Grebe & Company, Incorporated.

RADIO-RECEIVING APPARATUS of the superheterodyne type in which a single control is provided for securing straight line frequency variation in the receiving system.

1,589,927—A. E. BEATTIE, Manzanillo, Cuba. Filed April 7, 1925, issued June 22, 1926.

THERMIONIC VALVE having stout annular glass envelope with electrodes arranged therein for high power operation.

1,589,946—E. G. DANIELSON, San Francisco, California. Filed May 19, 1925, issued June 22, 1926. Assigned to E. T. Cunningham.

RADIO-TUNING DEVICE, where a plurality of condensers are geared together for simultaneous control.

1,589,979—D. G. McCAA, Lancaster, Pennsylvania. Filed June 25, 1924, issued June 22, 1926. Assigned to The Electric Apparatus Company.

RADIO SYSTEM, having a plurality of electron tube circuits arranged for reduction of static disturbances where signaling energy is received in a path having a natural period longer than the period of the received oscillations, the natural period of the path being changed by the effect upon the reactance thereof by regularly produced oscillations.

1,590,198—D. G. McCAA, of Lancaster, Pennsylvania. Filed January 19, 1925, issued June 29, 1926. Assigned to The Electric Apparatus Company.

RADIO SYSTEM for the separation of undesired signals from desired signals, where a receiving circuit is provided with a path having inductances in parallel with a circuit for selectively amplifying the energy traversing one of the inductances to vary its reactance to the said signaling energy.

1,590,224—L. C. BLUME, Chicago, Illinois. Filed June 28, 1923, issued June 29, 1926.

RADIO DETECTOR, in which a readily adjustable mounting is provided for the cat whisker on a U-shaped supporting member for establishing contact with a crystal.

1,590,236—H. GERNSBACK, New York City. Filed September 18, 1924, issued June 29, 1926.

CRYSTAL DETECTOR, where a contact device in the form of a flat spring is provided with a point which engages a crystal where the crystal is secured in a cup readily movable under the contact.

1,590,346—L. M. CLEMENT, East Orange, New Jersey. Filed September 25, 1920, issued June 29, 1926. Assigned to Western Electric Company.

RADIO DIRECTION FINDING, including a system of undamped wave transmission where a continuous wave is modulated in accordance with a wave having a cyclically and continuously varying frequency for insuring rectilinear propagation in all directions for selective reception on a directional receiver.

1,590,352—J. M. EGLIN, East Orange, New Jersey. Filed June 20, 1924, issued June 29, 1926. Assigned to Western Electric Company.

ELECTRON-DISCHARGE DEVICE, in which a getter is supported within the tube by a refractory metal ring extending from one of the electrodes for insuring a high degree of vacuum throughout the life of the tube.

1,590,374—L. C. F. Horle, Newark, New Jersey. Filed January 16, 1926, issued June 29, 1926. Assigned to Federal Telephone Manufacturing Corporation.

RADIO TRANSMISSION SYSTEM, which comprises generating at a control station a carrier wave of frequency above audibility but of comparatively low order of frequency for line wire transmission, which carrier wave is conveyed to the transmitting station and changed in frequency to produce a carrier wave of high frequency which is modulated for the transmission of signals.

1,590,678—W. FUHRMANN, Westfield, New Jersey. Filed April 7, 1925, issued June 29, 1926. Assigned to Furnell Manufacturing Corporation.

CONDENSER FOR ELECTRIC CIRCUITS, wherein a pair of evolute coil strips are arranged to be shifted one within the other for varying the exposure therebetween and correspondingly the electrical capacity between the strips.

D-70,407—ROBERT D. DUNCAN, JR., East Orange, New Jersey. Filed March 29, 1926, issued June 22, 1926. Assigned to Wired Radio, Incorporated, of New York City.

WIRED RADIO RECEIVING APPARATUS for the reception of programs broadcasted over line wire circuits.

1,589,692—E. E. HILER, of Bloomfield, New Jersey. Filed August 27, 1925, issued June 22, 1926. Assigned to Irvington Varnish & Insulator Company, of Irvington, New Jersey.

CHOKE COIL AMPLIFICATION UNIT, where a pair of choke coils are mounted upon a laminated iron core structure and housed within a casing.

1,590,428—ROBERT D. DUNCAN, JR., of East Orange, New Jersey. Filed August 25, 1925, issued June 30, 1926. Assigned to Wired Radio, Incorporated, of New York City.

WIRED RADIO BROADCASTING SYSTEM, in which high-frequency currents are super-imposed of line wire circuits and transmitted to a multiplicity of subscriber stations.

1,590,413—C. BOL and B. VAN DER POL, Eindhoven, Netherlands. Filed June 27, 1924, issued June 29, 1926. Assigned to N. V. Philips' Gloeilamphenfabrieken.

ELECTRIC DISCHARGE TUBE of high power construction arranged for cooling the electrodes during operation.

1,590,467—F. S. McCULLOUGH, Wilkinsburg, Pennsylvania. Filed December 11, 1922, issued June 29, 1926.

SPACE DISCHARGE DEVICE, including an evacuated vessel with elements therein and a circuit for producing extremely high potential from alternating current which is impressed upon the elements which are arranged for the rectification of the potential thus produced.

1,590,635—D. G. McCAA, Lancaster, Pennsylvania. Filed May 5, 1925 issued June 29, 1926. Assigned to The Electric Apparatus Company.

RADIO SYSTEM for the reception of signaling energy substantially free of of static disturbances. A balanced circuit is provided the adjustment of which is disturbed by incoming oscillations to effect operation of a responsive device to the exclusion of static disturbances.

ISSUED JUNE 22, 1926—AUGUST 31, 1926

1,507,120—C. H. TEEGARDEN, Buffalo, N. Y. Filed July 10, 1924, issued August 24, 1926.

INDICATOR MECHANISM for radio receiving apparatus, whereby the frequency setting for any particular station may be readily determined and logged for immediate adjustment of the receiver for the particular transmitting station.

1,597,247—E. C. RANDLE, Cincinnati, Ohio. Filed October 19, 1923, issued August 24, 1926.

RADIO INSIDE AERIAL, in which a strip is wound upon a rectangular frame in spiral formation and the turns are spaced from the frame for eliminating dielectric losses.

1,597,291—J. A. ROSEMOND, Charleston, South Carolina. Filed February 24, 1925, issued August 24, 1926.

CAPACITY UNIT, in which a plurality of condenser plates are mounted in compact relationship with plates of opposite potential, alternately positioned and secured upon bars which are substantially insulated from the plates.

1,591,177—E. MINGE, Chicago, Illinois. Filed May 22, 1922, issued July 6, 1927.

RADIO CONDENSER formed in a plug which may be screwed into an electric light socket. The condenser is formed by a plurality of separate insulated disposed in the plug.

1,592,834—G. W. LILIENTHAL, New York City. Filed April 21, 1925, issued July 20, 1926. Assigned to Wireless Radio Corporation.

CONDENSER, in which the rotor and stator plates are mounted upon the same end plate and insulated with respect to each other.

1,592,901—R. S. OHL, New York City. Filed May 23, 1924, issued July 29, 1926. Assigned to American Telephone and Telegraph Company.

OSCILLATOR for generating high frequency currents, in which a harmonic producing transformer having primary and secondary windings is arranged with its primary connected to a generator of low frequency oscillations and its secondary connected with a circuit tuned to a frequency which is a multiple of the frequency of said generator with a circuit for producing a sharp cut-off characteristic in the wave form produced in the secondary for securing shock excitation in the tuned circuit.

1,591,691—A. S. ALBRO, Washington, D. C. Filed September 12, 1922, issued July 6, 1926.

STATIC ELIMINATING SYSTEM, in which a Faraday cage is employed as part of the radio frequency energy collecting system and the receiving apparatus connected thereto, the cage acting as an unloaded vertical antenna.

1,591,717—J. W. MARDEN, East Orange, New Jersey. Filed September 28, 1922, issued July 6, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

ELECTRON EMISSION MATERIAL AND METHOD OF MANUFACTURE, wherein tantalum wire is provided with a uniform mixture of metallic tantalum and alkaline earth material.

1,592,075—B. BRUSKIN, Brooklyn, New York. Filed May 9, 1924, issued July 13, 1926.

ELECTRON TUBE, which includes a plurality of sets of electron tube elements within the same vessel. The patent relates to a particular construction of tube by which the elements are maintained in compact relationship.

1,592,234—J. SCOTT-TAGGART, Bolton, England. Filed October 26, 1920, issued July 13, 1926.

VACUUM TUBE FOR RADIO APPARATUS, in which the cathode is supported by means of a device fastened to a portion of the glass envelope.

1,592,272—M. J. KELLY, New York City. Filed April 13, 1923, issued July 13, 1926. Assigned to Western Electric Company.

ELECTRON DISCHARGE DEVICE for high power operation, wherein the electrodes are supported from a central tubular member within the tube by means of a collar which surrounds and grips the central tubular member.

1,592,364—W. G. HOUSKEEPER, New York City. Filed April 26, 1921, issued July 13, 1926. Assigned to Western Electric Company.

IONIZATION MANOMETER for measuring exceedingly minute pressures such as are present in vacuum tubes. Alternative positive and negative potentials are impressed upon the grid and plate electrodes, while maintaining one of the electrodes at a predetermined potential and measuring the resultant current in the circuits of the tube.

1,593,387—G. SEIBT, Berlin Schoneberg, Germany. Filed August 26, 1925, issued July 13, 1926.

ELECTRIC DISCHARGE TUBE, having a heated cathode and a plurality of grid like electrodes arranged in spaced and substantially parallel planes.

1,592,546—L. B. VICTOR, New York City. Filed May 14, 1924, issued July 13, 1926.

VERNIER PLATE CONDENSER, having rotor and stator elements arranged to be interleaved with respect to each other with an independent vernier plate arranged to be shifted with respect to the sets of plates for actively adjusting the capacity of the condenser.

1,592,554—A. A. BURNS, Elizabeth, New Jersey. Filed October 4, 1924, issued July 13, 1926. Assigned to Garod Corporation.

NEUTRALIZING CONDENSER for securing exceedingly fine degrees of capacity adjustment in amplifier circuits where the condenser consists of an interiorly threaded tubular member of insulating material with metallic bushings in opposite ends of the screw threaded tubular member adjustable with respect to each other for fixing the capacity of the condenser.

1,592,612—F. W. MEYER, Brunswick, Germany. Filed December 8, 1924, issued July 13, 1926. Assigned to General Electric Company.

RELAY SYSTEM, including an electron tube arranged to have the potential of its grid changed from a non-operative to an operative value in response to an operation which may be performed either manually or automatically for effecting the closing or opening of a circuit. The tube has a cathode and anode with an insulated grid there between with an ionizable medium having its pressure regulated to cause a relay to be operated at a predetermined time after the supply of energy to the tube circuits.

1,592,628—W. F. EINTHOVEN, Delft, Netherlands. Filed October 21, 1922, issued July 13, 1926. Assigned to Nederlansch-Indie.

RECEIVING OF RADIO SIGNALS, where an electrical circuit is provided for taking up the oscillations of a string galvanometer individually tuned mechanically to the radio frequency of the incoming signals. The vibrations of this string are observed for determining the signals.

1,592,710—J. SCOTT-TAGGART, Bolton, England. Filed July 5, 1921, issued July 13, 1926.

MODULATION SYSTEM, comprising a circuit in which the conductivity of a two-electrode rectifier to radio frequency currents is controlled by impressing low frequency modulating currents on the anode voltage and applying a steady negative potential thereto of a value which will substantially prevent the flow of radio frequency currents while no modulating currents are impressed upon the anode voltages.

1,592,738—N. LEA, Strand, London, England. Filed March 3, 1926, issued July 13, 1926.

ELECTRIC COUPLING DEVICE FOR THERMIONIC VALVES. which consists of a mounting which includes a condenser, a resistance winding wound on a bobbin and a removable resistance unit centrally positioned within the bobbin.

1,592,775—O. G. LISSEN, Jersey City, New Jersey. Filed January 12, 1924, issued July 13, 1926.

VARIABLE CONDENSER, comprising a plurality of stator plates and a plurality of sets of movable plates co-acting therewith where one set of movable plates has a greater capacity than the other. The movable plates may be either independently or simultaneously rotated.

1,592,925—F. CARBENAY, Paris, France. Filed April 4, 1924, issued July 20, 1926.

SYSTEM OF RADIO SIGNALING, in which a receiver is provided with a tapped inductance coil with socket members for the insertion of a plug by which desired portions of the inductance may be conveniently included in the circuit.

1,592,934—R. V. L. HARTLEY, East Orange, New Jersey. Filed May 29, 1918, issued July 20, 1926. Assigned to Western Electric Company.

MEANS FOR MODULATING HIGH FREQUENCY OSCILLATIONS, where the high-frequency oscillations are generated by an electron discharge device and a potential varying in audio frequencies is supplied to the plate circuit for controlling the operation of the transmitter.

1,593,033—G. M. PROUDFOOT, Chicago, Illinois. Filed Aug 1, 1924, issued July 20, 1926. Assigned to Cruver Manufacturing Company.

CASING FOR MECHANISM, in which a pair of end plates are provided with annular grooves into which a cylindrical side strip is disposed and engaged therein for enclosing the apparatus.

1,593,269—H. J. ROUND, London, England. Filed March 30, 1922, issued July 20, 1926. Assigned to Radio Corporation of America.

RADIO TELEGRAPHY, in which a number of short wave transmitting stations are arranged in such relation to each other that short gaps may be bridged by successive reception and re-radiation of the waves for establishing the long-distance communication channel.

1,593,276—J. McW. STONE, Chicago, Illinois. Filed December 1, 1924, issued July 20, 1926. Assigned to Operadio Corporation.

RADIO DIRECTION FINDER, which is combined with a magnetic compass by which the position of the loop may be determined at all times.

1,593,361—R. A. RIDENOUR, College Corner, Ohio. Filed June 28, 1924, issued July 20, 1926.

RADIO RECEIVING APPARATUS, including a plurality of electron tubes connected in selective circuits, in which the signal energy is initially partially detected and the undetected portion amplified, followed by the steps of redetecting the same wave and amplifying the ensuing audio frequencies.

1,593,483—M. YAMAMOTO, Glen Head, New York. Filed March 7, 1924, issued July 20, 1926.

ELECTRON DISCHARGE DEVICE, in which a plurality of sets of cylindrical electrodes are mounted within an electron tube by means of an insulated spacing member.

1,593,538—M. MATHIESEN, Chicago, Illinois. Filed May 29, 1925, issued July 20, 1926. Assigned to Mathiesen-Sandberg Company.

COLLAPSIBLE LOOP AERIAL, in which a series of turns are spaced upon a frame and the frame arranged to be folded for securing desired portability.

1,593,662—A. MEISSNER, Berlin, Germany. Filed September 3, 1921' issued July 27, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

SENDING ARRANGEMENT, in which undesired oscillations in the transmitting antenna are absorbed by a trap circuit while permitting the radiation of desired frequencies.

1,593,837—G. A. MATHIEU, London, England. Filed March 10, 1922, issued July 27, 1926. Assigned to Radio Corporation of America.

RADIO SIGNALING SYSTEM for the operation of a relay at a receiving station where a plurality of electron tubes are arranged in a stabilized circuit for the control of the relay without interference from undesired oscillations.

Re-16,385—Ralph Bown and Edward L. Nelson, East Orange, New Jersey. Original filed April 26, 1921; reissue filed June 4, 1926, issued July 20, 1926. Assigned to American Telephone and Telegraph Company.

RADIO WIRE CONNECTING CIRCUITS for establishing a link between wire lines and radio systems for permitting use of the telephone network as the connecting medium between a subscriber and the radio station by which both the line wire and space gap may be bridged in a communication channel.

1,594,060—J. HUFF, New York City. Filed June 21, 1918, issued July 27, 1926. Assigned to General Electric Company.

HOT FILAMENT MAGNETIC RECTIFIER, comprising an evacuated container with two electrodes capable of emitting electrons of an elevated temperature, and a cooperating electrode. An alternating current supply is connected across the two electrodes. A magnetic field is produced to direct the flow of electrons from each of the two electrodes to the cooperating electrode.

1,594,124—J. E. SHRADER, Edgewood Park, Pennsylvania. Filed December 13, 1920, issued July 27, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

CONDENSER, formed by a stack of alternate unimpregnated solid dielectric and conducting material which are secured under pressure and then subjected to a combined heat and vacuum treatment after which the condenser is impregnated with insulating compound.

1,594,179—S. LOEWE, of Berlin, Germany. Filed August 26, 1921, issued July 27, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

VACUUM TUBE, in which a plurality of paths of thermionic current are provided, one of the paths being arranged to control the operation of the other path for the production of oscillations.

1,594,846—E. F. NORTHRUP, Princeton, New Jersey. Filed June 18, 1917, issued August 3, 1926. Assigned to Ajax Electrothermic Corporation.

DISCHARGE GAP, in which there is arranged a solid electrode and mercury in the presence of air at approximately atmospheric pressure with a non-carbonizable vapor mingled with the air.

1,594,699—W. K. THOMAS, Crafton, Pennsylvania. Filed September 12, 1922, issued August 3, 1926.

RADIO RECEIVING SET, including a cabinet containing a detecting unit with guides formed within the cabinet, and a plurality of terminals in line with the guides so that terminals on the panel will cooperate with terminals on the cabinet for completing the electrical circuits.

1,594,700—A. G. TRIGG, London, England. Filed June 15, 1926, issued August 3, 1926.

VARIABLE CONDENSER FOR RADIO TELEPHONY, where rotatable plates are arranged for independent movement in the manner of a fan for varying the electrical capacity with respect to a set of stationary plates.

1,595,166—O. CHELLER, Berlin, Germany. Filed February 3, 1925, issued August 10, 1926. Assigned to C. Lorenz, Aktiengesellschaft.

MULTIPLE ANTENNA, in which a plurality of conductors are radially positioned and extend from a relatively high central point to lower elevations. Down leads are provided at points along the conductors in which inductances are interposed, the points of connection of the down leads decreasing in spaced relationship in proportion to the height of the conductor.

1,595,184—W. FUHRMANN, Westfield, New Jersey. Filed December 30, 1924, issued August 10, 1926. Assigned to The Furnell Manufacturing Corporation.

CONDENSER FOR ELECTRIC CIRCUITS, in which the movable and stationary plates comprise single flat strips of material curbed in the general form of an evolute arranged on frame structures for reciprocal motion of one coil with respect to the other.

1,595,729—A. PRESS, Wilkinsburg, Pennsylvania. Filed June 17, 1920, issued August 10, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

RECEIVING SYSTEM, in which an electron tube is provided having a grid plate circuit and a grid cathode circuit, the grid being rendered positive with respect to both the plate and cathode. The signal impulses in the grid cathode circuit affect the grid plate circuit to increase the amplitude of current therein, while during non-signaling periods the current in the grid plate circuit is reduced to a negligibly small value by the proper arrangement of the potentials on the tube electrodes.

1,595,730—A. PRESS, Wilkinsburg, Pennsylvania. Filed June 17, 1920, issued August 10, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

BALANCED REGENERATIVE DETECTOR, where an electron tube has two of its electrodes maintained at a common potential, while the third electrode is charged positively with respect to the common potential of the two electrodes, the electrodes being regeneratively coupled to improve sensitivity.

1,595,777—J. H. HAMMOND, JR., Gloucester, Massachusetts. Filed May 6, 1918 (original), issued August 10, 1926.

MEANS FOR CHANGING THE INTENSITY OF SIGNALS IN RADIODYNAMIC RECEIVING SYSTEMS, in which a leak path across the grid condenser is provided which consists of a thermionic valve in shunt with the grid condenser, whereby the functioning voltage of the shunt may be varied.

1,595,794—D. G. LITTLE, Edgewood Park, Pennsylvania. Filed June 30, 1921, issued August 10, 1926. Assigned to Westinghouse Electric and Manufacturing Company.

RADIO TELEPHONE SYSTEM, in which an electron tube oscillator circuit has bridged across the grid and plate elements thereof a circuit including a condenser and microphone, the microphone operating to vary the effective capacity of the condenser for modulating the oscillator.

1,595,810—C. T. ALLCUTT, Pittsburgh, Pennsylvania. Filed December 13, 1919, issued August 10, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

PLATE CONDENSER ELEMENT AND METHOD OF MANUFACTURE THEREFOR, in which the condenser plates are spaced by soft metallic members which may be pressed into such thickness that the plates are uniformly spaced apart and secured in position.

1,595,870—E. Y. ROBINSON, Manchester, England. Filed March 29, 1924, issued August 10, 1926. Assigned to Metropolitan-Vickers Electrical Company, Limited.

ELECTRIC VACUUM TUBE AND THE LIKE for high power operation where the failure of the supply of cooling waters to the anodes of the high power tubes is avoided by the provision of an auxiliary supply of cooling fluid. In the event that the main water supply becomes inoperative the auxiliary water supply is automatically placed in operation for saving the tube from destruction.

1,596,093—R. C. GALLETTI, Murs, France. Filed August 23, 1921, issued August 17, 1926.

SYNTONIZATION OF CIRCUITS USED IN RADIO SIGNALING, in which the characteristics of frequency and wave shape of the current in several circuits is completely in accord by the specific relation of the inductance capacity and resistance elements of the circuits.

1,596,198—S. LOEWE, Berlin, Germany. Filed March 19, 1921, issued August 17, 1926. Assigned to Western Electric.

SYSTEM FOR GENERATING OSCILLATIONS, in which an electron tube functioning both as an amplifier and an oscillator, is arranged in circuit with an antenna system for transmitting oscillations to the output circuit of the electron tube system at a frequency substantially independent of variations in the load.

1,596,374—W. H. PREISS, Belmont, Massachusetts. Filed June 6, 1921, issued August 17, 1926. Assigned to Wireless Specialty Apparatus Company.

ELECTRICAL CONDENSER AND METHOD OF MAKING THE SAME, in which a stack of condenser sections are secured under pressure within a casing with a heat radiating member extending from the upper pressure plate for preventing undue rise in temperature in the condenser.

1,596,636—A. H. TAYLOR, Washington, D. C. Filed July 2, 1920, issued August 17, 1926. Assigned to Wired Radio, Incorporated.

RADIO RECEIVING CIRCUIT, in which antennae of differing characteristics are extended in opposite directions and connected adjacent their inner ends with receiving apparatus with a circuit at the receiver for rendering the reception highly directional and receptive in one directior while non-receptive in the opposite direction.

1,596,692—A. LUCKASH, Morann, Pennsylvania. Filed February 5, 1924, issued August 17, 1926.

AUDION TUBE, in which the electrodes are supported on annular frame structures concentrically arranged within the electron tube.

1,596,875—L. A. HAMMARLUND, New York, N. Y. Filed Fenruary 14, 1924, issued August 24, 1926. Assigned to Hammarlund Manufacturing Company.

VARIABLE CONDENSER, in which the rotor shaft may be moved through small increments by means of a rock shaft independent of the rotation of the rotor shaft.

1,596,984—A H. MARKS, New York, N. Y. Filed March 26, 1923, issued August 24, 1926.

METHOD AND APPARATUS FOR BROADCASTING, in which the performer is enabled to listen to the results of actual reception at a broadcast receiver for thereby securing the proper expression of the compositic n being transmitted.

1,597,379—F. A. KOLSTER, Washington, D. C. Filed May 29, 1919, issued August 24, 1926. Assigned to Federal Telegraph Company.

RADIO METHOD AND APPARATUS for transmission and reception systems, in which a closed circuit including capacity and a divided inductance coil for absorbing energy directly from the media is provided. A coupling coil is connected between the parts of the inductance coil and in series with the closed circuit. Receiving apparatus is connected to the coupling coil and an antenna is connected to a point intermediate the terminals of the coupling coil. The circuit permits selective reception of signals in a particular direction.

1,597,398—L. T. WILSON, West Somerville, Massachusetts. Filed May 1, 1920, issued August 24, 1926. Assigned to Powel Crosley, Jr.

OSCILLATION CIRCUIT, including a plate circuit having two plates, a cathode circuit and a grid circuit with a transformer arranged to have its primary connected to the alternating current source and having the ends of its secondary connected with the plates. The grid circuit is tapped into the secondary of the transformer in such manner that the voltage in the grid circuit is opposite to the voltage applied to the plate circuit.

1,597,416—C. B. MIRICK, Washington, D. C. Filed September 1, 1923, issued August 24, 1926.

ELECTRICAL DISTANT CONTROL SYSTEM for effecting the operation of any desired circuits of a plurality of circuits at a distant receiver from a transmission station. The transmitter is modulated at different frequencies for effecting transmission of different control signals and at the receiver these signals actuate particular relays to the exclusion of other relays for controlling a particular circuit.

1,597,431—W. B. BURGESS, Washington, D. C. Filed May 14, 1923, issued August 24, 1926.

RADIO RECEPTION SYSTEM, wherein the capacity effect of the leads from the electron tube amplifier circuits of the receiver to the batteries is substantially eliminated by interposing radio frequency choke coils in the battery leads so that radio frequency is eliminated from the battery supply system.

1,597,591—F. G. FREESE, Aldan, Pennsylvania. Filed February 6, 1925, issued August 24, 1926.

RADIOCONDENSER, in which the plates of a variable condenser may be apertured for decreasing the metallic area of the plate exposed to each other for fixing the capacity of the condenser.

1,597,643—C. P. WIEGNER, Donnellson, Iowa. Filed January 19, 1925, issued August 24, 1926.

RADIOTUBE, including a base from which a U-shaped member projects for supporting the electrodes within the tube structure.

1,597,764—G. H. CLARK, Brooklyn, New York. Filed July 1, 1922, issued August 31, 1926. Assigned to Radio Corporation of America.

ARC GENERATOR, where the arc discharge takes place within an enclosed chamber to which volatile liquid is supplied, and liquid is fed to the arc by a drip gravity feed system from a vessel where the pressure is equalized with respect to the pressure in the arc chamber.

1,597,825—V. D. Renwick, Camden, New Jersey. Filed October 16, 1924, issued August 31, 1926.

DETECTOR of the crystal type for mounting upon the rear of a panel to which a plurality of conductors establish contact with the rectifying element within a hermetically closed casing.

1,597,829—H. J. ROUND, London, England. Filed June 12, 1922, issued August 31, 1926. Assigned to Radio Corporation of America.

OSCILLATION GENERATOR, in which a rotary commutator having a plurality of segments and brushes are connected in separate circuits for building up increments of current into oscillations.

1,597,835—J. E. SHRADER, Pittsburgh, Pennsylvania. Filed May 24, 1921, issued August 31, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

LEAKY CONDENSER, in which a coil is wound upon an electrode, but insulated therefrom, the electrode serving as one terminal and the coil serving as the opposite terminal.

1,597,848—R. A. WEAGANT, New York, N. Y. Filed October 6, 1920, issued August 31, 1926. Assigned to Radio Corporation of America.

METHOD AND APPARATUS FOR RADIO SIGNALING, in which two antennæ of different types are employed and the signal and static currents geometrically combined for eliminating the effects of the static currents.

1,597,893—H. K. HUPPERT, San Francisco, California. Filed June 11, 1924, issued August 31, 1926.

RADIO TUBE, including a pair of sets of independent electrodes supported by means of Y members within the tube.

1,597,910—M. LOCK, Berlin, Germany. Filed December 5, 1922, issued August 31, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

CONTROLLING ARRANGEMENT FOR TUBE SENDERS SUPPLIED WITH ALTERNATING CURRENT, in which an inductive resistance is connected in the plate circuit and a direct current circuit coupled to the inductive resistance for magnetizing it and varying the value of the resistance for the production of signals.

1,598,000—J. NILSON and J. F. PRINCE, Chicago, Illinois. Filed October 1, 1924, issued August 31, 1926.

RADIO CONDENSER ADJUSTMENT, wherein a number of variable condensers are operated simultaneously through a system of gears.

1,598,226—P. WARE, New York, N. Y. Filed February 8, 1918 (original), issued August 31, 1926. Assigned to Ware Radio, Incorporated.

DUPLEX CUT-IN SYSTEM OF RADIO TELEGRAPHY, where the two inter-communicating stations are arranged for continuous wave oper-

ation and signals are transmitted on different frequencies and the receiver is provided with an oscillator for producing oscillations for combining with the incoming oscillations. The sending key controls both the outgoing oscillations and the detecting means to enable simultaneous radiation of oscillations and reception of incoming signals with the key in determined position, said key controlling the transmission of signals.

1,598,227—P. WARE, New York, N. Y. Filed February 8, 1918 (original), issued August 31, 1926. Assigned to Ware Radio, Incorporated.

CUT-IN SYSTEM OF RADIO TELEGRAPHY, whereby simultaneous transmission and reception may be effected from the same antenna-ground circuit. The transmitting key controls the receiver in such manner that incoming signals can only be normally detected when the key is in normal position for sending signals.

1,598,144—A. LEIB, Berlin, Germany. Filed May 3, 1922, issued August 31, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

RADIO RECEIVING APPARATUS, for determining direction of incoming signals in which a circuit which includes a balancing antenna and a loop circuit which are employed for securing accuracy in the location of the transmitter.

1,598,526—L. A. JENNY, Dumont, New Jersey. Filed May 17, 1924, issued August 31, 1926.

RADIO TUNING DEVICE, in which the inductance coils of a tuning circuit are disposed about an electron tube for the purpose of reducing the length of the connectors to a minimum.

1,591,019—R. C. DA COSTA, Philadelphia, Pennsylvania. Filed April 2, 1920, issued July 6, 1926. Assigned to Atwater Kent Manufacturing Company.

CONDENSER AND HOLDER THEREFOR for automobile ignition systems, in which a rolled condenser is secured within a holder by means of a resilient bearing member.

1,591,025—R. D. DUNCAN, JR., East Orange, New Jersey. Filed July 24, 1925, issued July 6, 1926. Assigned to Wired Radio, Incorporated.

DUPLEX RADIO TELEPHONE SYSTEM, by which signals may be transmitted and received on closely adjacent antennæ systems without interference from side tones. A three-phase high frequency source is provided at the transmitter and one of the phases is impressed upon the receiving system for neutralizing the effects of the components of the other phases of the source upon the receiving apparatus.

1,591,131—J. J. JAKOWSKY, Pittsburgh, Pennsylvania. Filed April 30, 1924, issued July 6, 1926. Assigned one-fourth to A. B. McCall.

DIELECTRIC SUPPORTING PLATE FOR VARIABLE AIR CONDENSERS, wherein a strip of skeleton formation is secured to the stator plate supports for providing bearings for the rotor plates with minimum dielectric losses.

D-70,750—WILLIAM H. GERNS, East Orange, New Jersey. Filed May 25, 1926, issued August 3, 1926. Assigned to Brandes Laboratories, Incorporated.

DESIGN FOR POWER SPEAKER CABINET, in which the complete power equipment and cone speaker is housed as a portable unit for connection to the output circuit of a radio receiving apparatus.

1,597,711—WALLACE A. BARTLETT, London, England. Filed September 19, 1925. Issued August 31, 1926. Assigned to Brandes Laboratories, Incorporated.

ADJUSTABLE ELECTROMAGNETIC SOUND REPRODUCERS, where the electromagnetic driving force is adjustable with respect to the sound reproducing diaphragm. The structure of this patent is the feature of the adjustable table talker developed by the Brandes organizations.

PROCEEDINGS OF
The Institute of Radio Engineers

Volume 14 DECEMBER, 1926 Number 6

CONTENTS

At the end of this number are the title page, page of general information and Table of Contents pages for the entire Volume 14 (1926) of the PROCEEDINGS. These last may be suitably placed at the beginning of the volume for binding.

GENERAL INFORMATION

The PROCEEDINGS of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings and at the Sections in the several cities listed on the following page.

Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership.

Subscriptions to the PROCEEDINGS are received from non-members at the rate of \$1.50 per copy or \$9.00 per year. To foreign countries the rates are \$1.60 per copy or \$9.60 per year. A discount of 25 per cent is allowed to libraries and booksellers.

It is understood that the statements and opinions given in the PROCEEDINGS are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

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INSTITUTE ACTIVITIES

Lloyd P. Smith

Mr. Lloyd P. Smith, the author of the paper entitled "Theory of Detection in a High Vacuum Thermionic Tube," which appeared in the October, 1926, issue of the PROCEEDINGS is connected with the Research Department of the General Electric Company, at Schenectady, New York.

Membership Committee

The Membership Committee, H. F. Dart, Chairman, held a meeting at Institute headquarters on the evening of November 9th. The committee has completed plans looking to a considerable increase in the membership throughout the midwestern states.

Sections Committee

The Sections Committee, David H. Gage, Chairman, held a meeting at Institute headquarters on the afternoon of November 4th. The committee has been making a thorough study of the entire Sections situation with a view to strengthening the ties between the Sections and Institute headquarters and with the object of rendering all assistance possible to Section officers in carrying on the work.

Chicago Section

The Chicago Section held a meeting on the evening of October 29th. in the rooms of the Western Society of Engineers, Chicago. A paper was delivered by Lieut. Fred H. Schnell on the subject "Transmission and Reception on Short Waves." The paper dealt with the experiences of Lieut. Schnell while in charge of the Short Wave Station of the U. S. Navy during a cruise across the Pacific to Australia. The talk was illustrated with lantern slides.

At this meeting a Membership Committee was appointed, made up of J. H. Miller, F. J. Marco, and G. S. Turner.

Washington Section

The Washington Section held a meeting on the evening of November 10th in the Conference Room, 8th floor, Department of Commerce Building, 19th and Pennsylvania Avenue, Washington. A talk was given by Dr. A. Hoyt Taylor on the subject "Recent Developments in High Frequency."

Dinner Precedes New York Meetings

Members of the Institute and their engineer guests who attend the regular meetings in New York, have been foregathering at The Fraternities Club, Madison Avenue and Thirty-seventh Street, for dinner. Dinner is served at 6:30 P. M., at $1.25 per plate.

The attendance at dinner ranges from sixty to eighty-five members.

The meetings are held on the first Wednesday of each month, excepting July and August. Also, the January meeting each year is held simultaneously with the Annual Convention.

October Meeting in New York

At the October 6th meeting held in the Engineering Societies' Building, New York, a paper was presented by Dr. Alfred N. Goldsmith, on the subject "Reduction in Interference in Broadcast Reception." The paper was illustrated by lantern slides.

About two hundred and fifty members were present.

Canadian Section

The Canadian Section, Toronto, held a meeting at the University of Toronto on September 24th, jointly with the Toronto Section of the A. I. E. E.

A paper was presented by Professor T. R. Rosebrugh, entitled: "A-c.—d-c. Rectification for Radio Uses," and one by Professor H. W. Price entitled: "Elementary Mathematical Consideration of Flter Circuits."

Oscillographic demonstrations supplemented by loud speaker reproductions were given by Professor Price.

The Section held a meeting on October 6th, at which Mr. F. K. Dalton, of the Hydro-Electric Power Commission gave a talk on: "Radio Applications of the Hydro-Electric Power Commission."

Discussion was participated in by C. L. Richardson, Dr. Lucas, G. F. Pipe and others.

Membership Committee

The Membership Committee held a meeting at Institute headquarters on the evening of October 4th. Those present were. H. F. Dart, Chairman, R. S. Kruse, W. G. H. Finch, M. Berger and President McNicol, ex-officio. The committee has done excellent work this year as is reflected by the fact that there has been a net gain of thirty per cent in members for the year.

Section Facilities

Members of the Institute should make note of the names and addresses of Section officers so that when opportunity presents, on visits to the cities where Sections are organized, contacts may be formed which should benefit the members and the Institute.

October Board Meeting

At the October 6th meeting of the Board of Direction the following were present: D. McNicol, President, R. Bown, Vice-president, A. N. Goldsmith, Secretary; W. F. Hubley, Treasurer; J. H. Dellinger, Past President and L. A. Hazeltine, L. E. Whittemore, L. Espenschied, R. H. Marriott, Melville Eastham, Managers.

The Board approved the election of 78 Associates and 3 Juniors.

The report of the Admissions Committee was approved passing for transfer to Member grade: F. H. Schnell, J. F. Andrews, B. E. Shackleford, E. W. Lovejoy, E. W. Dunton, L. J. N. Du Treil, K. S. Van Dyke. Also direct election to Member grade: E. H. Ullrich, Dr. George Seibt and F. G. Wright.

Annual Convention

The personnel of the Convention Committee which will arrange for the annual meeting and convention to be held about the middle of January is: Douglas Rigney, Chairman, and Meade Brunet, L. M. Clement, Q. A. Brackett, P. H. Boucheron, J. H. Dellinger, D. G. Casem, J. D. R. Freed, H. F. Dart, O. E. Dunlap, Keith Henney, W. E. Harkness, W. G. H. Finch, I. K. Rodman, M. C. Rypinski, W. A. Winterbottom, U. B. Ross, and F. E. Eldredge.

Committee on Drafting Room Practice

At the invitation of the American Engineering Standards

Committee, the Institute has appointed a representative on a Committee which will undertake the task of setting up Standards for Drawing and Drafting Room Practice. Mr. L. E. Whittemore will serve as the Institute's representative.

Los Angeles Section

The Los Angeles Section held a meeting in classrooms of the Y. M. C. A., Los Angeles, on the evening of September 20th. A paper was presented by Mr. H. Pratt on the subject "Problems of The Radio Engineer."

Philadelphia Section

The Philadelphia Section held a meeting on September 17th for the purpose of electing new officers for the coming year. Forty-five members were present. The result of the election was that J. C. Van Horn was elected chairman and David P. Gullette Secretary-treasurer. At this meeting a paper was presented by Mr. T. R. Kennedy on the subject of "Radio Compass Installation."

A meeting of the Section was held on October 22nd at which Mr. Halborg read a paper on the subject of "Short Wave Communication." The meetings of the Section are held in the Bartol Laboratories, Philadelphia.

Committee on Broadcast Engineering

As announced in the October PROCEEDINGS, the Board of Direction approved the appointment of a Committee on Broadcast Engineering. The members of this committee are R. H. Marriott, Chairman, and Messrs. L. Espenschied, L. A. Hazeltine, Frank Conrad and John H. Miller. It will be noted that three members of the committee are also members of the Board of Direction.

The purpose of the Institute's Committee is to establish an authority to which technical questions relating to broadcasting may be referred for report. The Institute's non-commercial position and prestige are such that it is the only body equipped to render accurate and unbiased decisions on radio engineering subjects.

Sectional Committee on Radio, A.E.S.C.

This Committee, organized some time ago, with Professor J. H. Morecroft as chairman and Dr. A. N. Goldsmith as secretary,

[illegible] on the various important problems involved in planning [illegible] for radio manufacture and installation.

Entrance Fee

On page 15 of the 1926 Year Book, Article IV, Dues, the entrance fee payable on admission to the Institute, covering each grade is given. During the past three or four years the entrance fee has been waived, but is to be restored on January 1, 1927, as stated in Article IV. Those who join the Institute, any grade, after January 1, 1927, shall be required to pay the proper entrance fee, as well as the annual dues, as soon as they are notified of their election to membership.

Philadelphia Section

The Philadelphia Section held a meeting on the evening of October 22nd in the rooms of the Bartol Laboratory, 127 North 19th Street, Philadelphia. A very interesting talk was given by Mr. H. E. Hallborg on the subject "High Power Transmitters at Wavelengths Varying from Fifteen to Ninety Meters." The Section plans to hold regular meetings during the winter months.

Proceedings to be Issued Monthly

The present plan is to begin monthly publication of the PROCEEDINGS, beginning with the January, 1927 issue. All members will receive the monthly issues as heretofore they have received the bi-monthly issues, without any additional dues payment. This increase in the number of copies of the PROCEEDINGS, which members receive annually, will be of very great advantage and value.

Hartford Section

An organization meeting was held at Hartford, Connecticut, on the evening of October 29th for the purpose of setting up a Section of the Institute to cover the State of Connecticut with headquarters at Hartford.

After the business meeting was concluded a highly interesting address was delivered by E. F. W. Alexanderson, consulting engineering, General Electric Company, and chief consulting engineer of the Radio Corporation of America. Mr. Alexanderson's talk was on the subject "Radio Photography." Motion pictures and lantern slides were used in illustration.

San Francisco Section

The San Francisco Section held a meeting on the evening of September 23d at the Engineers' Club, 57 Post Street, San Francisco. A talk was given by Dr. F. A. Kolster on the subject "Some Notes in the Design of Radio Receiving Equipment." A talk was also given by R. M. Heintz on the subject "Modern Short Wave Radio Equipment." These papers were discussed by Col. J. F. Dillon, A. H. Babcock, Major Bender, F. G. Roebuck. The Section also held a meeting on the evening of October 27th at which a paper was presented by Dr. L. F. Fuller on the subject "Carrier Current Communications Over High Tension Transmission Lines."

Rochester Section

The Rochester Section held a meeting on the evening of November 19th, Mr. Harold A. Wheeler from Johns Hopkins University spoke on the subject of "Applications of Electron Tube Amplifiers." A meeting to be held on December 3d will be addressed by Mr. W. A. McDonald of the Hazeltine Corporation on the subject "Importance of Laboratory Measurements in Radio Receiver Design." The meeting to be held on January 7th will be addressed by Mr. F. H. Engel, of the Radio Corporation of America, who will speak on "Vacuum Tubes."

The Section holds its meetings in the rooms of the Rochester Engineering Society, in the Sagamore Hotel.

November Meeting in New York

At the regular November meeting held in New York, a paper was presented by J. C. Warner and A. V. Loughren, on the subject "The Output Characteristics of Amplifier Tubes."

Admissions Committee

At the October 29th meeting of the Admissions Committee the following Associates were recommended for transfer to Member grade: W. K. Glasby, C. W. Richard, W. L. Holst, E. S. Farnsworth and W. J. Lee. For direct election to Member grade the following were recommended: H. D. Hineline, J. Svoboda and A. E. Thompson.

Seattle Section

The Seattle Section held a meeting on September 4th, in the

... room of the Telephone Building. A paper was presented by Mr. Alex Hallman on the subject "Radio Conditions in The ...ment." Also a paper by Mr. J. Tolmie on the subject "Two-... Bridge Oscillator." The discussion was participated in by John Greig, T. Libby and J. Tolmie.

A local Membership Committee was appointed consisting of E. B. Wilson, T. Libby, and J. Tolmie.

The Section held a meeting on the evening of October 2d at which Mr. Howard F. Mason gave a talk on the subject "Radio with the Detroit Expedition."

The meetings of the Section are attended by about thirty members.

Meetings and Papers Committee

The Meetings and Papers Committee, R. H. Marriott, Chairman, which arranges for all papers, meetings and the dinner at the Fraternity Club preceding the meetings, holds its meetings at those dinners beginning about one hour before the arrival of the other members. The speakers of the evening meet with this Committee. Occasionally members have come to these dinners alone and have not found any person they knew. Beginning with the December meeting the table used by this Committee will be placed near the door so that a member of the Committee will be able to meet such strangers and introduce them to other members.

THE OUTPUT CHARACTERISTICS OF AMPLIFIER TUBES*

By
J. C. Warner and A. V. Loughren
(Research Laboratory, General Electric Company)

It has long been common practice to define the capabilities of an amplifier tube in terms of certain constants or characteristics, such as mutual conductance, amplification constant, input impedance and output resistance. As long as the primary interest is in the *amplification* which the tube will give in a definite circuit a few such quantities furnish all of the information necessary for determining the performance of the tube, but when the tube is to supply an appreciable amount of power to the load circuit they are entirely inadequate.

Improvements in loud speaker design have almost invariably increased the demand on the tube which is supplying the power to the loud speaker. It has been necessary to increase the output of the tube or decrease the distortion caused by the tube itself, or both. It has become important, then, to have an accurate knowledge of the maximum undistorted output which the tube can supply.

In order to bring out the distinction between the *maximum output* of an amplifier tube and the *maximum amplification*, it may be well to review briefly some of the different methods of using amplifier tubes in radio receiving circuits. The terms "voltage amplifier," "current amplifier" and "power amplifier" are often used to distinguish the general types of amplifiers, although all of these, strictly speaking, are *power* amplifiers, since the power controlled in the output circuit is always larger than the power supplied to the input of the tube. However, the terms "voltage amplification," "current amplification," etc., may be used correctly to indicate the performance of a tube in a particular circuit. Other performance characteristics which are sometimes important are the "current output per volt input" and the "power output per volt squared input." Of these quantities the

*Received by the Editor, April 16, 1926. Presented at a meeting of the Institute of Radio Engineers, New York, N. Y., November 3, 1926.

ones most often used are perhaps the two last named and the voltage amplification.

The voltage amplification is

$$A_v = \frac{\mu R_p}{R_p + r_p} \tag{1}$$

where μ = amplification constant

r_p = internal plate resistance

R_p = load resistance

The current output per volt input is

$$A_{cv} = \frac{\mu}{R_p + r_p} \tag{2}$$

The power per volt squared input is

$$A_{pv} = \frac{\mu^2 R_p}{(r_p + R_p)^2} \tag{3}$$

It may be noticed that the mutual conductance, $\frac{\mu}{r_p}$, does not appear directly in any of these relations. This illustrates the fact that the amplification of a tube is not directly proportional to the mutual conductance, although this factor is often used as a "figure of merit" for the tube. The only justification for this is that tubes designed for the same sort of service can be roughly compared by the mutual conductance, but when the amplification constant or plate resistance differs greatly—that is, of the order requiring a different type of load circuit—a comparison of mutual conductance loses its significance.

Factors Determining Amplification

Equation (1) shows that for a given value of μ and r_p the voltage amplification increases when R_p is increased and approaches μ in the limit. Practical circuit limitations usually prevent R_p from going much over 500,000 ohms and the amplification is seldom over 75 percent of μ. With an inductive load it is, of course, possible to approach much closer to the full value of μ.

In order to illustrate the effect of the tube constants on the amplification, three sets of curves have been drawn, which show the relation between the amplification constant of a tube and the actual amplification in terms of voltage, current and power. A cylindrical electrode structure, similar to that used in the UX-199 Radiotron, was taken for these examples and it was assumed that the amplification constant was varied by changing the grid mesh, no other structural change being made. Figure 1

shows the variation in the plate resistance of this type of tube when the amplification constant is varied.

Figure 2 gives the relation between μ and the voltage amplification for several values of load resistance. The decrease in amplification with low load resistance at the higher values of μ, is, of course, due to the fact that r_p rises more rapidly than μ. Otherwise all of the curves would rise indefinitely.

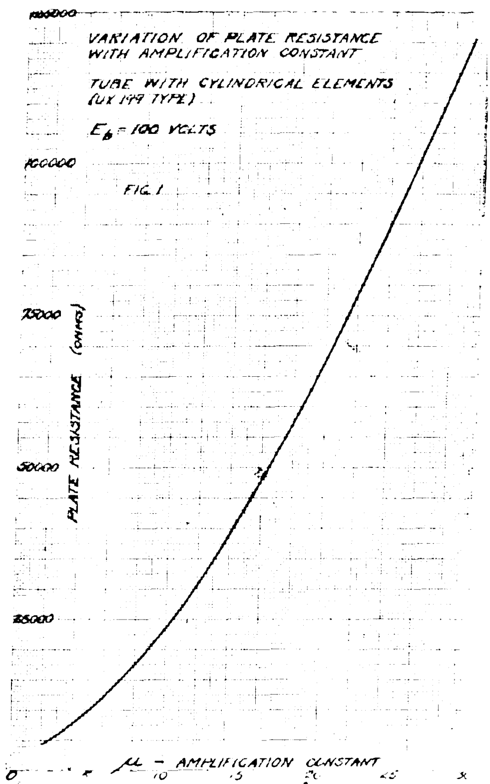

FIGURE 1

Figure 3 shows the variation in current output per volt input for different load resistances.

The relation between μ and power output per volt squared input is shown in Figure 4. The envelope of the curves for fixed load resistances gives the output for a variable load resistance, which is kept equal to the plate resistance of the tube. It is interesting to note that if the tube resistance is fixed, the maximum power per volt squared is obtained when the load resistance is made

equal to the tube resistance, but if the load resistance is fixed, the tube resistance should be made considerably higher than the load resistance. It will be seen later that neither of these conditions holds for maximum undistorted power output when sufficient input voltage is available.

Use of Plate Characteristic Curves for Calculating Output

The above relations between input voltage and output voltage, current and power, hold only when the amplitudes

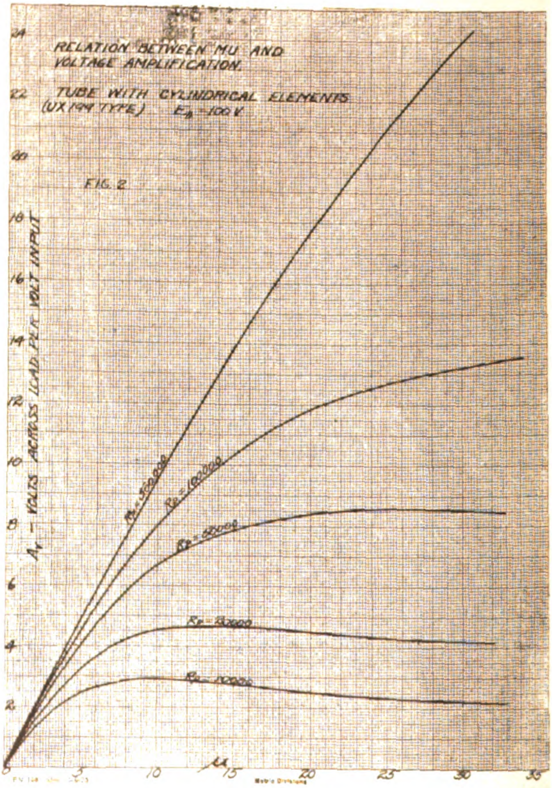

FIGURE 2

are small. This condition usually exists in all but the last tube of an amplifier, but in this tube the amplitudes must be large, since the power supplied to the loud speaker is often considerable. It then becomes necessary to determine the output characteristics of the tube feeding the loud speaker, and in particular it is

desirable to know the *maximum power output* which the tube will supply without distortion.

The usual method of determining the output of a tube when the amplitudes are large involves drawing the complete dynamic characteristic, which is a rather laborious process when a large number of different conditions are to be considered. A much

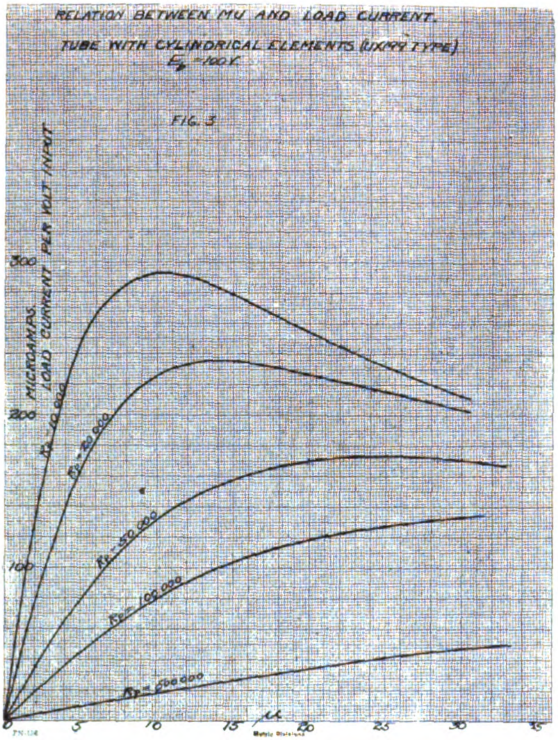

FIGURE 3

simpler method gives all of the information furnished by the dynamic curve, and in the rare cases when the dynamic curve is required it may be drawn easily from the data obtained by the simpler method.

This method of analysis makes use of the family of plate voltage-plate current curves as shown in Figure 5, and combines these static characteristics with the load characteristic in such a way as to show the current and voltage at any instant.

The method was worked out primarily for a circuit in which the load resistance is in series with the supply voltage, as in Figure 6. However it applies equally well to a circuit in which the plate

voltage is supplied through a choke or where the load is coupled through a transformer, provided the mean current does not change greatly when the signal is applied. Since this corresponds to the conditions for low distortion the method may be applied safely to the cases where the load is not in series with the plate supply voltage as long as the distortion does not rise above the limit which should be permitted in practice.

Referring again to Figure 5, the plate current at any instant

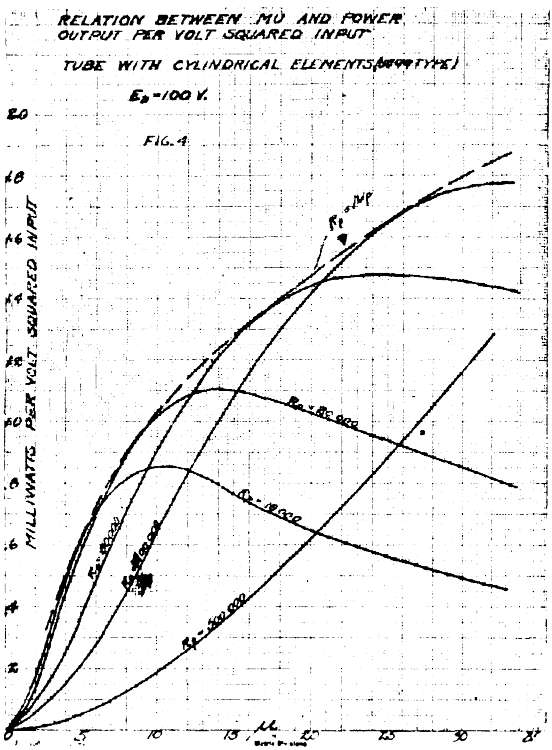

Figure 4

is determined by the voltages on plate and grid, and the plate voltage in turn is determined by the battery voltage and the $I\,R$ drop in R_p. These conditions can be expressed by two equations:

$$i_p = f(v_p, \mu\, v_g) \tag{4}$$

$$v_p = E_b - i_p R_p \tag{5}$$

Since the first equation is not linear and can not be easily expressed, the simplest solution is graphical. The typical plate

voltage-plate current curves of Figure 5 are plotted from equation (4) by assigning arbitrary fixed values of v_g and plotting the $v_p - i_p$ curves from experimental data. Now if equation (5) is plotted the intersection of its graph with one of the plate current curves gives the plate current for that particular value of grid

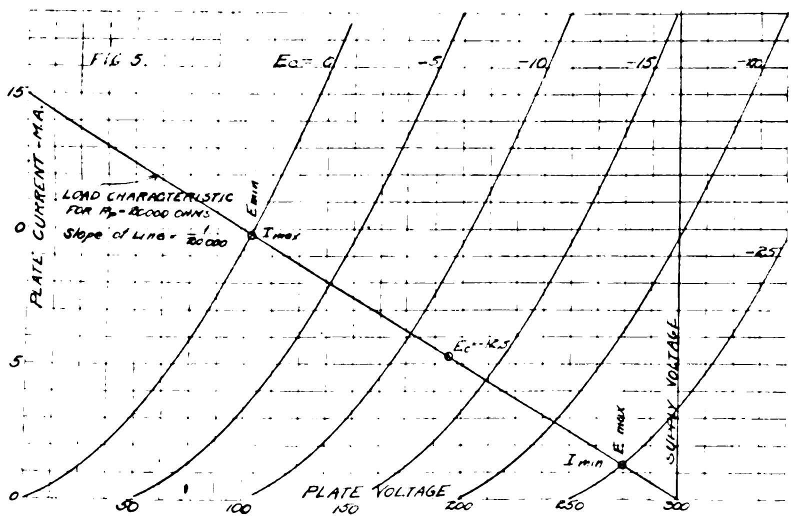

FIGURE 5—Tube and Load Characteristics

voltage. The slope of the load characteristic is, of course, equal to the reciprocal of the load resistance.

Conditions for Maximum Output with Low Distortion

In order to prevent distortion in a tube certain conditions must be satisfied: First, the grid must not be allowed to become

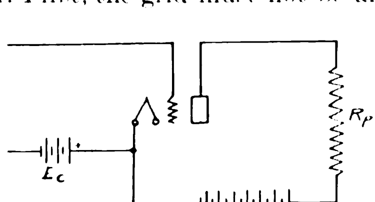

FIGURE 6—Amplifier Circuit

sufficiently positive to draw appreciable grid current, and, second, the plate current must at no portion of the cycle be allowed to fall to so low a value that distortion is caused by curvature of the dynamic characteristic.

Distortion results from the grid becoming positive because the input circuit usually has rather high impedance, and during the time when the grid is positive current flows through this impedance reducing the voltage at the tube by the amount of the voltage drop in the impedance. Grid current flows during one-half of the cycle only and the grid terminal voltage wave is, therefore, flattened or otherwise distorted on this half cycle.

The second condition—that the plate current must not decrease below a certain point—may be shown either theoretically or experimentally to be necessary if the tube is to produce only a small amount of harmonic current. This is rather obvious from the shape of the characteristic curves, but will be brought out more fully later.

With these two conditions, and making certain simplifying assumptions, it has been shown by W. J. Brown* that the maximum undistorted output is obtained when the load resistance is equal to twice the internal resistance of the tube. In proving this relation Brown has made use of the grid voltage-plate current static characteristic, but for the sake of simplicity the writers have preferred to show the proof with the plate voltage-plate current characteristics, although the method is otherwise essentially the same as that used by Brown.

In determining the conditions for maximum output several assumptions must be made. As has just been stated, the grid must not at any time be allowed to become sufficiently positive to take current and the plate current swing must be confined to that part of the dynamic characteristic which does not have excessive curvature. Further, the grid bias must be allowed to take the value corresponding to the optimum condition, and for the purpose of calculating the conditions for maximum output the static characteristics are assumed to be straight over the range used. These first three assumptions are clearly justified both in determining the optimum conditions and the actual output, although the second involves a definition of the allowable distortion. The last assumption, of course, cannot be made when the actual output is to be calculated, but is justifiable in determining the conditions for maximum output.

Figure 7 shows another family of static plate voltage-plate current characteristics for different grid voltages, which will be used in illustrating the method of determining maximum output conditions. These are drawn as straight lines above the hori-

*Proc. of Phys. Soc. of London. Vol. 36, Part 3, April 15, 1924, p. 218.

zontal line marked "I_{min}," this being the region to which the current swing is confined. I_{min} represents the lowest plate current at any time in the cycle. E_o represents the d-c. plate voltage, measured at the tube.

A straight line, A B, whose slope is the reciprocal of the load resiatance is drawn across the family of curves. This must be drawn in such a way that the grid voltage at the point where it crosses the E_o line is half the grid voltage of the point where it

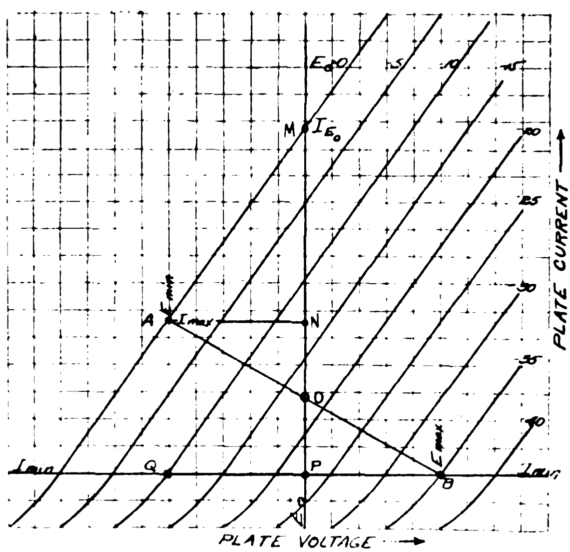

FIGURE 7—Tube Characteristics for Showing Conditions for Maximum Understorled Output

crosses the I_{min} line. The ends of this line then give I_{max} and I_{min} as well as E_{max} and E_{min}, which are the instantaneous plate voltages and currents at the ends of the swing. The grid bias is the grid voltage at which the line A B crosses the E_o line; the grid swings to zero on the one side and to twice the bias on the other.

The output power is

$$P = \frac{1}{8}(E_{max} - E_{min})(I_{max} - I_{min}) \tag{6}$$

and the load resistance is

$$R_p = \frac{E_{max} - E_{min}}{I_{max} - I_{min}} \text{ or } \frac{BQ}{AQ} \tag{7}$$

If I_{E_0} is the plate current at a plate voltage equal to E_o and grid bias of zero, the internal resistance of the tube is

$$r_p = \frac{1}{2}\frac{(E_{max} - E_{min})}{I_{E_o} - I_{max}} \text{ or } \frac{1}{2}\frac{B\,Q}{M\,N}$$

and

$$E_{max} - E_{min} = 2r_p(I_{E_o} - I_{max})$$

$$P = \frac{1}{4} r_p (I_{max} - I_{min})(I_{E_o} - I_{max})$$

Since E_o is fixed

$$(I_{max} - I_{min}) + (I_{E_o} - I_{max}) = const. \text{ or } N\,P + M\,N = const.$$

Then P is maximum when $I_{max} - I_{min}$ is equal to $I_{E_o} - I_{max}$ or $N\,P = M\,N$
but since

$$I_{max} - I_{min} = \frac{E_{max} - E_{min}}{R_p} \text{ or } N\,P = A\,Q$$

and

$$I_{E_o} - I_{min} = \frac{E_{max} - E_{min}}{2\,r_p}$$

$$R_p = 2\,r_p \tag{8}$$

or the load resistance is equal to twice the internal resistance.

It will be noticed that this condition is not the same as the condition for maximum amplification in watts per volt squared input. Lowering the load resistance would tend to raise the output but would at once cause distortion, since the plate current swing would fall below the previously assigned value of I_{min}.

The above-mentioned method of determining the maximum output neglects plate power dissipation as a possible limitation, in a large power amplifier. If the value of I_o is found to be so large that the product $E_o I_o$ exceeds the allowable plate loss, the conditions must be modified. When a signal is impressed on the amplifier and an output is produced, the plate loss is less by that amount, but it is not permissible to take advantage of this as an amplifier is ordinarily subject to silent periods during which the entire plate circuit input is expended in heating the plate. A similar limitation occurs in a receiving tube when I_o is too large for the safe operation of the tube or approaches too near to the total electron emission from the filament.

In order to reduce $E_o\,I_o$, E_o may be decreased—and incidentally I_o—or I_o alone may be decreased. Figure 8 shows power output, I_o, and plate dissipation for the UV-211 tube ($\mu = 12$), plotted against plate voltage. Two curves are shown for each

quantity, one for best conditions with the given plate voltage, the other for such grid bias as gives a plate circuit input of 75 watts. It is assumed throughout that the peak value of the grid swing is equal to the grid bias; that is, that the grid potential varies from zero to $-2\,E_c$, when maximum power is demanded from the amplifier. The lower set of curves shows the plate circuit input increasing quite rapidly with voltage. As it passes the

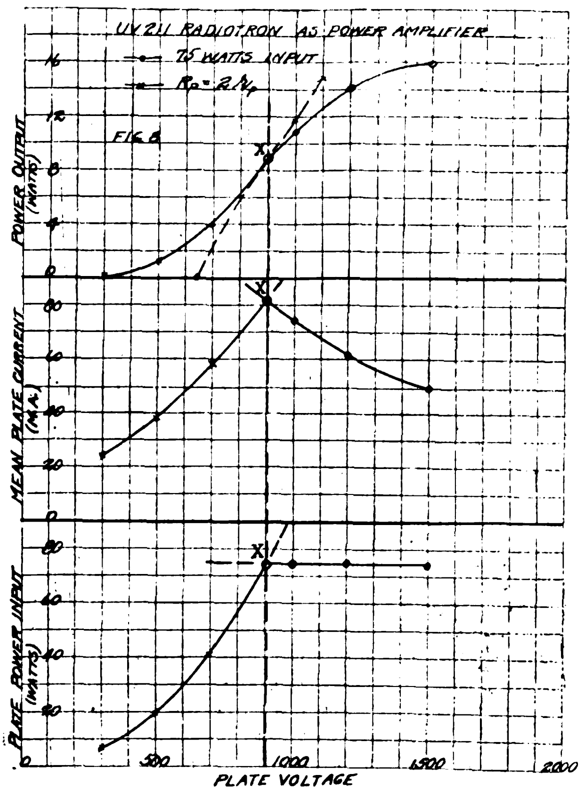

FIGURE 8

75-watt point the operation is shifted to the other curve, on which input is constant. The next set of curves above shows the static value of plate current as a function of plate voltage. At the point at which the dissipation reaches 75 watts, the operating point shifts from a rising curve to the hyperbola $E_o\,I_o = 75$, shown on the right hand side of the vertical broken line. The upper set of curves shows the power obtainable under each condition (*i.e.*, constant plate input of 75 watts and maximum output) as a function of plate voltage. From these it may be seen that it is best simply

to decrease I_o by increasing the grid bias rather than to decrease E_o, and consequently I_o, in case the plate circuit input is too high. For example, suppose that it is desired to operate this tube at 1,100 volts. The dissipation under maximum output conditions is over 100 watts—too high, accordingly, as the tube is rated at 75 watts anode dissipation. The output would be 15 watts. Now if E_o is decreased until the dissipation is 75 watts, the output (at point X) is 9 watts, and the plate voltage about 900. But if E_o is maintained at 1,100 and the plate current is reduced to 0.068 by increasing the grid bias, the output is 12.5 watts—a 40 per-cent gain over the power at the point X.

Calculatuon of Maximum Output

The calculation of the maximum undistorted output will next be illustrated in detail, with consideration of the case where there are no restrictions as to grid bias and plate current as well as those cases where certain restrictions apply. Figure 9 shows a

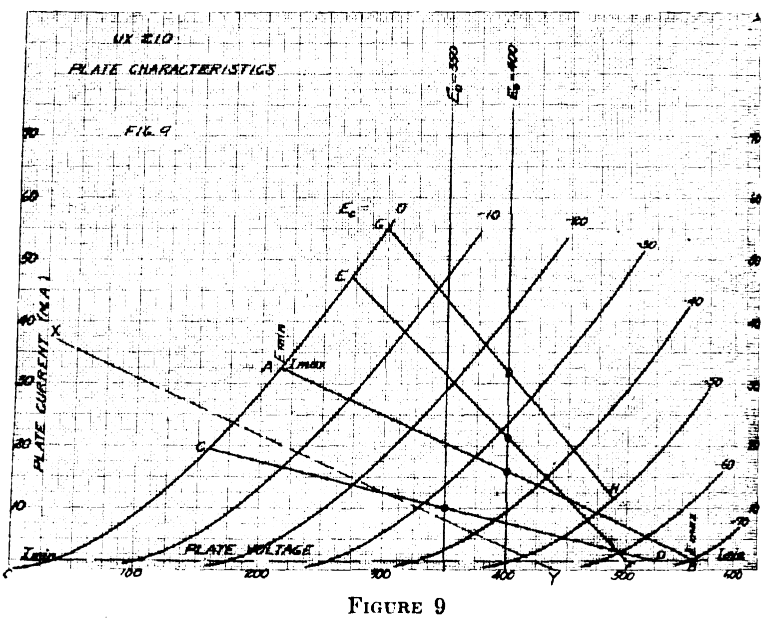

Figure 9

family of plate voltage—plate current curves for the UX-210 Radiotron which will be used for these illustrations. This tube has been designed for use as an oscillator or as an amplifier for plate voltages not exceeding 400 volts. As an oscillator the tube is rated at 7.5 watts output, and the safe plate power dissipation

is 12 to 15 watts, depending somewhat on the conditions of use.

The complete procedure is as follows:

(1) The family of plate voltage—plate current curves must be drawn for negative grid voltages up to at least twice the maximum grid bias which is to be used. This point can usually be estimated after a preliminary examination of the first characteristics drawn. It is not necessary to plot all of the curves from experimental data. The curve for zero grid voltage and one or two negative voltages should be drawn from experimental data; then as the amplification constant of the tube is known the other curves may be drawn in.

(2) The minimum plate current—that is, the plate current at the negative end of the grid voltage swing—must next be determined. The exact choice of this is dependent partly on the load resistance which is to be used and partly on the amount of distortion which is allowable. Since "allowable distortion" is difficult to define, the value of I_{min} is best chosen arbitrarily. After the output characteristics have been found the percentage of harmonic current in the output can be calculated (only the second harmonic need be considered) and if it is too high a second calculation may be made with a higher value of I_{min}. I_{min} may be from 1/10 to 1/5 of I_o in most of the ordinary types of tubes when the second harmonic current is not allowed to exceed 5 per cent of the fundamental.

It is usually convenient to draw a horizontal line corresponding to I_{min} across the characteristics; then only that part of the curve family which is above this line is to be used.

(3) There are now four methods of procedure, depending on the predetermined conditions as to plate voltage, mean plate current, grid voltage, etc., and also the relation of the tube constants to these conditions.

It is assumed that the plate voltage is predetermined according to the maximum safe voltage which can be applied to the tube in question or according to the supply voltage available.

Case I. Given:

D-C. Plate Voltage (E_o)
Minimum Plate Current (I_{min})

To find:

Load Resistance (R_p)
Grid Bias (E_c)
D-C. Plate Current (I_o)
Power Output

Under these conditions the maximum output will be obtained as previously explained when the load resistance is equal to twice the plate resistance of the tube. The tube resistance itself varies somewhat, depending on the grid bias ultimately chosen, but a sufficiently close estimate of the final mean plate current can be made in order to find the point where the plate resistance is to be calculated. For example, it is reasonable to suppose that the direct-plate current of the UX-210 at 400 volts plate voltage will be about 15 milliamperes and the plate resistance at this current is found to be 5,500 ohms. (If the actual current is found later to be much different from 15 milliamperes a second approximation will be necessary). A straight line, XY, whose slope is equal to the reciprocal of the load resistance— *i.e.*, 11,000 ohms—is now drawn across the family of curves to serve as a guide. This line is not absolutely necessary, but is a matter of convenience to make it easier to locate the final load line.

Next, another straight line, AB, is drawn parallel to XY, beginning on the $E_b - I_b$ curve for $E_c = 0$ and ending on the I_{min} line. This must cross the E_o line at a value of E_c, which is exactly half the value of E_c at the point where it crosses the I_{min} line. Thus AB crosses the E_o line at $E_c = -35$ and the I_{min} line at $E_c = -70$. I_o is 16 milliamperes.

This straight line AB furnishes all of the desired information for instantaneous voltage and current, power output and per cent second harmonic current.

$$E_{max} = 560 \text{ volts}$$
$$E_{min} = 215 \text{ volts}$$
$$I_{max} = 32.5 \text{ milliamperes}$$
$$I_{min} = 1.5 \text{ milliamperes}$$
$$\text{Power Output} = 1/8\,(560-215)\,(32.5-1.5) \times 10^{-3}$$
$$= 1.34 \text{ watts}$$

The ratio of second harmonic current to the fundamental in the plate circuit with a resistance load in series with the plate is

$$\frac{\frac{1}{2}(I_{max}+I_{min}) - I_o}{I_{max} - I_{min}} = \frac{17-16}{31} = \frac{1.0}{31} = 3.2 \text{ per cent.}$$

From the above results it can be seen that the best conditions for undistorted output from the UX-210 at 400 volts on the plate are:

$R_p = 11{,}000$ ohms. $E_c = -35$ volts. $I_o = 16$ milliamperes.

The alternating grid voltage (signal) is $\frac{\sqrt{2}}{2} \times 35$, or 24.8 volts r.m.s.

Case II. Given:

D-C. Plate Voltage (E_o)
Minimum Plate Current (I_{min})
Direct Plate Current (I_o)
(With large power tubes it is usually the plate power input ($E_o I_o$) that is fixed rather than I_o alone.)

To find:

Load Resistance (R_p)
Grid Bias (E_c)
Power Output

This case differs from Case I only when the value of I_o as calculated for Case I comes out above the allowable maximum for the tube. (This maximum current is the direct current under the operating conditions but with no signal, and should not be confused with I_{max} which refers to the peak value of current during the swing.)

For example, it will be assumed that the plate voltage is 350 volts on the UX-210 and that the direct current must be limited to 10 milliamperes. This immediately fixes a point on the E_o line through which the load characteristic must pass. E_c for this point is -33 volts. The lower end of the load characteristic must cross I_{min} at $E_c = -66$ volts. These two points then fix the line $C\,D$ from which the required output data can be obtained as follows:

$$E_{max} = 525 \qquad I_{max} = 19.5$$
$$E_{min} = 160 \qquad I_{min} = \ 1.5$$

$$\text{Power Output} = 1/8 \times 365 \times 18 \times 10^{-3}$$
$$= 0.822 \text{ watt}$$

$$\text{Load Resistance} = \frac{365}{18} \times 10^3 = 20280 \text{ ohms}$$

The signal voltage is 23.4 volts r.m.s.

Case III. Given:

Plate Voltage (E_o)
Load Resistance (R_p)
Minimum Plate Current (I_{min})

To find:

Grid Bias (E_c)
Plate Current (I_o)
Power Output

The procedure here is exactly the same as for Case I, excepting that the load resistance instead of being the optimum value is previously fixed. Assuming plate voltage 400 and a load resistance of 5,000 ohms, a line is drawn with a slope of $\frac{1}{5000}$; this intersects the E_o line at a grid voltage which is one-half the voltage at the point where it crosses the I_{min} line. This is the line EF; the grid bias is 31.5 volts and the direct plate current 21.5 milliamperes.

$$E_{max} = 500 \text{ volts} \qquad I_{max} = 47$$
$$E_{min} = 272 \text{ volts} \qquad I_{min} = 1.5$$
$$\text{Power Output} = 1/8 \times 228 \times 45.5 \times 10^{-3}$$
$$= 1.3 \text{ watts}$$

In this case the second harmonic current is nearly 15 per cent of the fundamental—an amount which is likely to be excessive. To decrease the distortion the calculations leading to the choice of grid bias and load resistance may be repeated with a higher value of I_{min}, say 6 or 8 milliamperes. This would reduce the harmonic to a reasonable value, although at the expense of a small reduction in the power output.

Case IV. Given:

Plate Voltage (E_o)
Grid Voltage (E_c)

To find:

Load Resistance (R_p)
Power Output

In this case it is assumed that the grid bias is fixed and cannot be adjusted to the optimum value. If the plate current corresponding to this grid voltage is equal to or less than that found by the method given for Case I, the methods of Case I or Case II may be used. If the plate current is more than that found for Case I the procedure is slightly different.

Referring again to Figure 9 it will be assumed that the plate voltage is 400 and the grid bias is -25 volts. This fixes the operating point at once and shows the direct plate current to be 32 milliamperes. The problem then becomes to find the load resistance which will give the highest output for a signal voltage of 17.7 volts r.m.s. Since the input voltage is fixed the condition that $R_p = 2r_p$ no longer gives the maximum output and the oad resistance should be decreased until $R_p = r_p$, or until the plate current swings down to I_{min}.

At $E_o = 400$, $E_c = -25$, r_p is equal to 4350 ohms. The line GH shows the load characteristic for a resistance equal to this. Since at $E_c = -50$ the line $G\,H$ does not go below the I_{min} line it represents the optimum condition. If H had gone below I_{min} it would have been necessary to raise R_p in order to prevent distortion.

The output characteristics then are:

$$E_{max} = 488 \qquad I_{max} = 55.$$
$$E_{min} = 300 \qquad I_{min} = 11.6$$

$$\text{Power Output} = 1/8 \times 188 \times 43.4$$
$$= 1.02 \text{ watts}$$

Relation of Design of Tubes to Power Output

A study of the characteristics of tubes having the same general dimensions—*i.e.*, electrode areas and spacings—but different values of amplification constant, shows that in general the lower the amplification constant the higher will be the maximum output obtainable from the tube even though the amplification is lower. This, of course, is the result of lowering the plate resistance, which can be done only by lowering the amplification constant at the same time. It is assumed that the load impedance can be varied to fit the tube impedance and that the same plate voltage is used in each case. This may be easily understood in a qualitative way by referring again to the power equation

$$P = \frac{\mu^2 E_g^{\,2} R_p}{(r_p + R_p)^2}$$

and if

$$R_p = 2r_p$$

$$P_{max} = \frac{2\mu^2 E_g^{\,2}}{9r_p} \tag{9}$$

Now, if μ is decreased E_g may be increased at least as rapidly without causing distortion. At the same time r_p decreases, even if the mean plate current is kept constant, thus causing an increase in P_{max}. Actually E_g may usually be increased more rapidly than μ is decreased, making a still greater increase in P_{max}.

Figure 10 illustrates this variation of maximum output with amplification constant in a larger power amplifier tube of the UV-211 Radiotron type. The straight line represents the output with a fixed plate power input of 75 watts. The curved line represents the output with no limit on input. However, under

the latter condition the plate power loss would overheat the tube if μ were lowered much below 16.

One of the most common uses for a power amplifier tube is in connection with a radio receiving set for supplying power

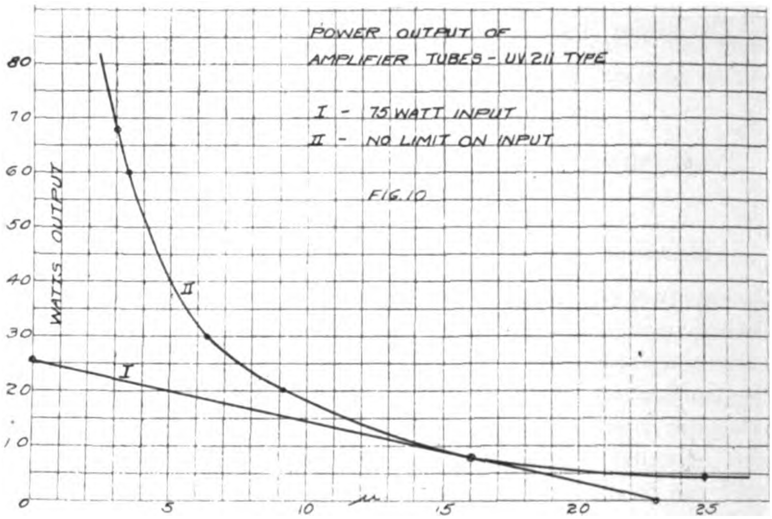

FIGURE 10

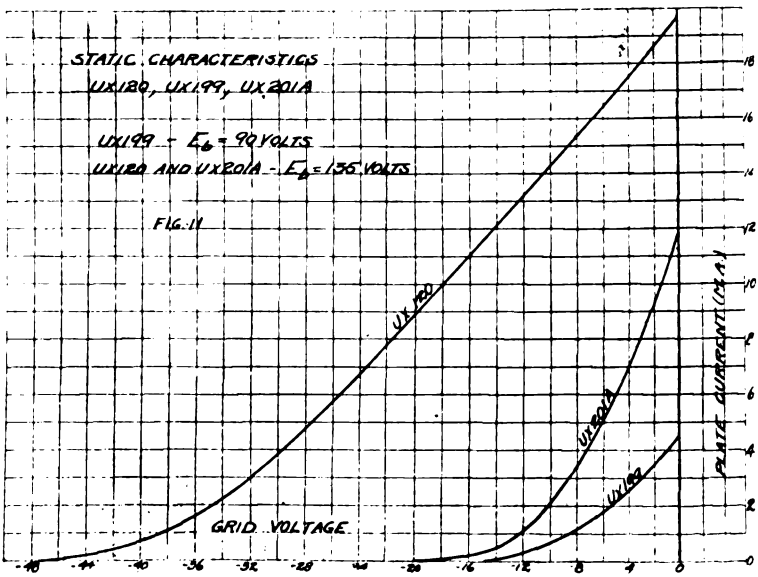

FIGURE 11

to the loud speaker. Recent improvements in loud speakers have increased the importance of high output and low distortion from the last tube in the amplifier. Three Radiotrons have been developed lately to meet the demand for a tube for this class of service. These are the UX-120, the UX-171 and the UX-210. The characteristic curves of the UX-210 have been used to illustrate the methods of determining the output.

It has been pointed out that increasing the plate voltage

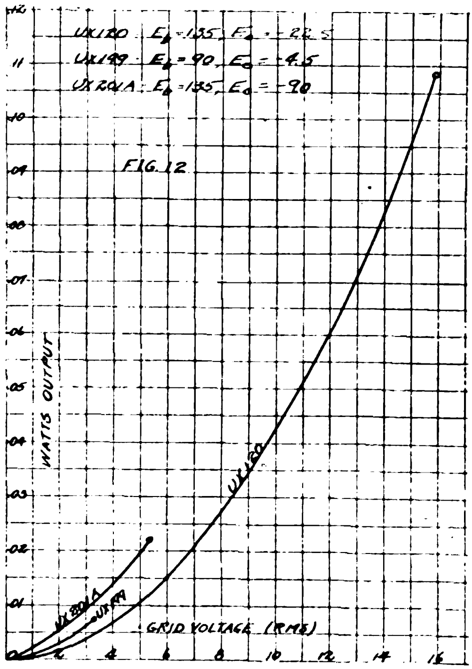

FIGURE 12—Input Voltage—Undistorted Power Output—Load Resistance 10,000 Ohms

increases the maximum output rapidly. The UX-210 is an example of a tube designed for operation at relatively high plate voltage and capable of supplying a large amount of power to a loud speaker without distortion. However there are many cases where the high plate voltage and filament power required by this tube are not available. For instance, it is often desirable to operate a set entirely from dry batteries, in which case both the filament power and the plate voltage are limited. The UX-120 has been developed for this purpose.

The UX-120 has a filament requiring 3 volts and 0.125 am-

pere. This voltage allows operation in parallel with other dry battery tubes such as the UX-199.

The noticeable features of this tube are the low amplification constant, averaging 3.3, and the high grid bias—22.5 volts. The reason for these values has already been explained. The maximum output is much greater than can be obtained from the UX-199, as a result of the higher plate voltage and the lower amplification constant and plate resistance.

Figure 11 gives a comparison of the static grid voltage-plate

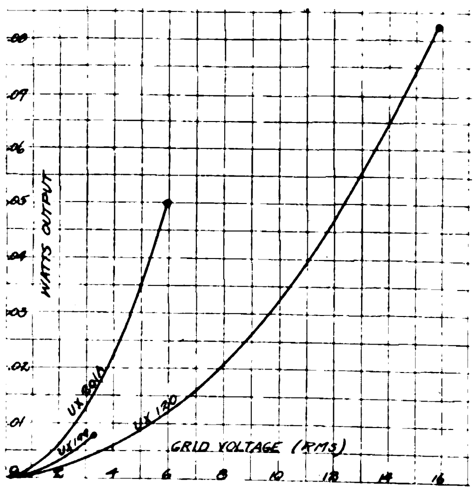

FIGURE 13—Input Voltage—Undistorted Power Output—Load Resistance 20,000 Ohms
UX 120 —$E_b = 135$, $E_c = -22.5$
UX 199 —$E_b = 90$, $E_c = -4.5$
UX 201A —$E_b = 135$, $E_c = -9.0$

current characteristics of the UX-199, UX-201-A and UX-120, each at its normal plate voltage.

Figures 12 and 13 show the relation between the input voltage and output power up to the distortion limit. Figure 12 is drawn for a load resistance of 10,000 ohms and Figure 13 for 20,000 ohms. It will be noticed in each case that the curves for the UX-199 and UX-201-A rise rapidly at first, due to the higher amplification, but are limited at relatively low input voltages either by the grid becoming positive or by excessive curvature of the plate current characteristic.

The third power amplifier tube, the UX-171, is intermediate in size and output between the UX-120 and UX-210.

The UX-171 has a 5-volt, 0.5 ampere filament and can be operated at plate voltages up to 180 volts. At this voltage the grid bias required is approximately −40 volts. The amplification constant is approximately 3 and the plate resistance is of the order of 2,000 to 2,500 ohms under usual operating conditions. Thus the UX-171 fills a place with reference to the UX-201-A much the same as the UX-120 with reference to the UX-199. Figure 14 shows static and dynamic characteristics of the UX-171. Figure

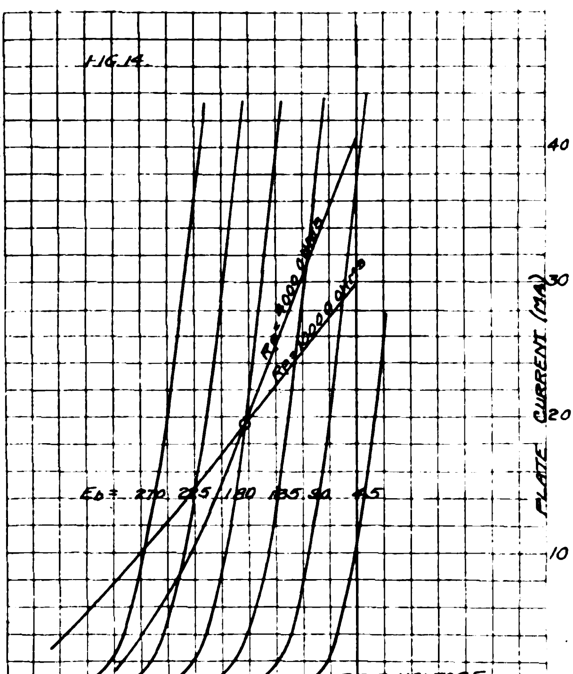

FIGURE 14—Static and Dynamic Characteristics—UX 171

15 gives the relation between a-c. input voltage and output power for load resistances of 4,000 and 10,000 ohms.

Table I gives a tabulation of some of the constants of the more commonly used Radiotrons. The first half of the table shows the constants of the tubes themselves. The second half gives the maximum undistorted output (assuming not more than 5 percent second harmonic current in the load), the load resistance at which the maximum output is obtained, the input grid voltage

required to produce this output, and the amplification of the tube with this same load resistance.

As has already been pointed out, analytical methods are not accurate for calculating the maximum power output. For this reason the product of the quantity A_p—the power output per

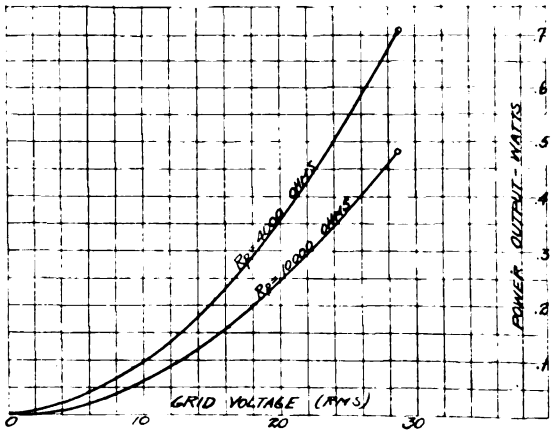

FIGURE 15—Power Output – UX 171
$E_b = 180 \quad E_c = -40.5$

volt squared input—and the square of the r.m.s. grid voltage for P_{max} will not always check exactly the figure given for P_{max} itself, as this latter was obtained in every case by graphical methods.

	Plate Voltage	Grid Bias	D.-C. Plate Current (Milliamperes)	Amplification Factor	Plate Resistance (Ohms)	Mutual Conductance (Micromhos)	(Micromhos)	Load Resistance	$\frac{\mu}{R_p + r_p}$ Output Current per Volt (Microamperes)	$\frac{\mu R_p r}{R_p + r_p}$ Output Voltage per Volt Input	$\frac{\mu^2 R_p}{(R_p + r_p)^2}$ Output Power per Volt Squared Input (Milliwatts)	A-C Grid Voltage (R.M.S) for P_{max}	Maximum Undistorted Output (Milliwatts)
Tube	E_b	E_c	I_b	μ	r_p	g_m	$\frac{\mu^2}{r_p}$	R_p	A_c	A_v	A_p	E_g	P_{max}
UX-199	90	— 4.5	2.5	6.5	15250	425	2770	15250	212	3.25	.690	3.18	7
	90	— 7.5	1.3	6.45	19250	335	2160	32000	126	4.00	.505	5.30	14
UX-201-A	90	— 4.5	2.0	8.5	12000	708	6000	15000	315	4.70	1.480	3.18	14
	90	— 6.0	1.2	8.4	15400	550	4620	30000	185	5.55	1.025	4.24	17
	135	— 9.0	2.55	8.4	11000	764	6410	22000	255	5.60	1.430	6.36	55
UX-120	135	—22.5	7.0	3.3	6600	500	1650	6360	250	1.65	.412	15.90	105
	135	—26.7	5.5	3.2	7500	427	1365	15000	142	2.13	.302	18.90	110
UX-171	90	—16.5	10.0	3.0	2350	1275	3820	4000	472	1.89	.893	11.58	105
	135	—27.0	16.0	2.9	2100	1380	4000	4000	475	1.90	.902	19.10	320
	180	—40.5	20.0	2.9	2000	1450	4200	4000	483	1.93	.934	28.60	710
UX-210	135	— 9.0	5.0	7.5	8000	940	7050	15000	326	4.89	1.59	6.36	64
	250	—18.0	11.5	7.5	5600	1340	10050	11000	451	4.97	2.25	12.72	340
	400	—35.0	16.0	7.5	5400	1390	10400	11000	457	5.03	2.30	24.80	1340
UV-203-A	1000	—22.5	26.0	25.0	8800	2840	71000	17600	947	16.70	15.80	15.90	3920
UV-211	1000	—48.5	75.0	12.0	3400	3530	42400	6800	1177	8.00	9.41	34.30	11000

NOTES ON THE DESIGN OF RESISTANCE-CAPACITY COUPLED AMPLIFIERS

By

Sylvan Harris

The function of the inter-stage coupling devices used in low frequency amplifiers is to transfer the alternating voltage developed in the output circuit of one amplifier by the action of an alternating voltage on the input of that tube, to the input of a second amplifier, with the utmost fidelity. The matter of amplification will not be considered in this paper excepting insofar as it is related to the voltage ratio of the coupling device at various frequencies.

The need for the "distortionless" amplifier, in the laboratory, in public address systems, and in radio transmitting and receiving apparatus, is evident, and it is desirable to know to what extent the operation of an actual amplifier may differ from that of the perfect amplifier. In other words, it may be possible to design an amplifier which is "distortionless" for practical purposes, and it is the purpose of this paper to consider the matter from this angle.

The low-frequency amplifier in receivers actuates a reproducer; if the pressure established in the air by the diafram of the loud-speaker or telephone receiver is assumed to be a linear function of the output voltage of the amplifier, the latter can be studied with regard to the auditory sensation, by noting that the ear, over a very wide range of sound intensity, is sensitive to changes of intensity of approximately ten per cent, and that this seems to be true regardless of frequency.*

Although for many purposes a variation of ten per cent in the voltage ratio of an amplifier from one frequency to another may be excessive, this figure will be used for purposes of illustration. There is also to be considered the commercial phase of the problem, where a compromise is required between results and

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* Bell System Tech. Jour., October, 1923. "Physical Measurements of Audition," Harvey Fletcher.

costs. The problem then is to find the required conditions in an amplifier coupling device under which the voltage ratio will not change more than 10 per cent from very high audible frequencies down to an arbitrary cut-off frequency. A cut-off frequency of 50 cycles per second was used in calculating the curves given here.

The wiring diagram of the resistance-capacity coupled amplifier in its simple form is shown in Figure 1, together with the equivalent circuit in Figure 1A. The voltage V_g is the output

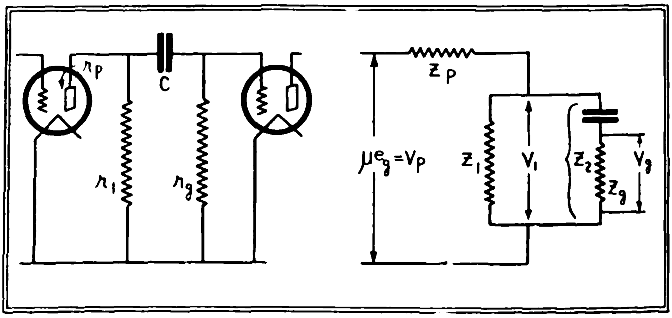

FIGURE 1 FIGURE 1-A

voltage of the coupling device and is impressed on the input of the second tube. V_p is the voltage input to the coupling device and equal to the voltage impressed on the input of the first tube multiplied by the voltage amplification constant of that tube or μe_g. The solution of Figure 1A follows:

$$\frac{V_g}{V_p} = \frac{V_g}{V_1} \times \frac{V_1}{V_p}$$

$$\frac{V_g}{V_1} = \frac{Z_g}{Z_2}$$

$$\frac{V_1}{V_p} = \frac{\dfrac{Z_1 Z_2}{Z_1 + Z_2}}{Z_p + \dfrac{Z_1 Z_2}{Z_1 + Z_2}} = \frac{Z_1 Z_2}{Z_p Z_1 + Z_p Z_2 + Z_1 Z_2}$$

$$\frac{V_g}{V_p} = \frac{1}{\dfrac{Z_p}{Z_g}\left[1 + \dfrac{Z_2}{Z_1}\right] + \dfrac{Z_2}{Z_g}} \tag{1}$$

Substituting the vectorial impedance as represented in Figure 1, the relation between V_g and V_p for the resistance-capacity coupled amplifier is

$$K = \frac{V_g}{V_p} = \frac{1}{\frac{r_p}{r_g}\left[1 + \frac{r_g - j/\omega c}{r_1}\right] + \frac{r_g - j/\omega c}{r_g}}$$

The absolute value of K is then:

$$K = \frac{1}{\sqrt{\left[\frac{\frac{r_1 r_g}{r_1 + r_g} + r_p}{\frac{r_1 r_g}{r_1 + r_g}}\right]^2 + \frac{1}{\omega^2 r_g^2 C^2}\left[\frac{r_p}{r_1} + 1\right]^2}} \qquad (2)$$

The maximum voltage ratio is obtained when C is infinite. Equation (2) then reduces to

$$K_{max} = \frac{\frac{r_1 r_g}{r_1 + r_g}}{\frac{r_1 r_g}{r_1 + r_g} + r_p} \qquad (3)$$

which is independent of frequency. The physical significance of this is apparent; the maximum voltage ratio is the ratio of the joint resistance of r_1 and r_g in parallel, to the sum of this joint resistance and r_p.

Equations (2) and (3) are shown plotted in Figures 2 and 3. It is desired to make the voltage ratio at a given cut-off frequency,

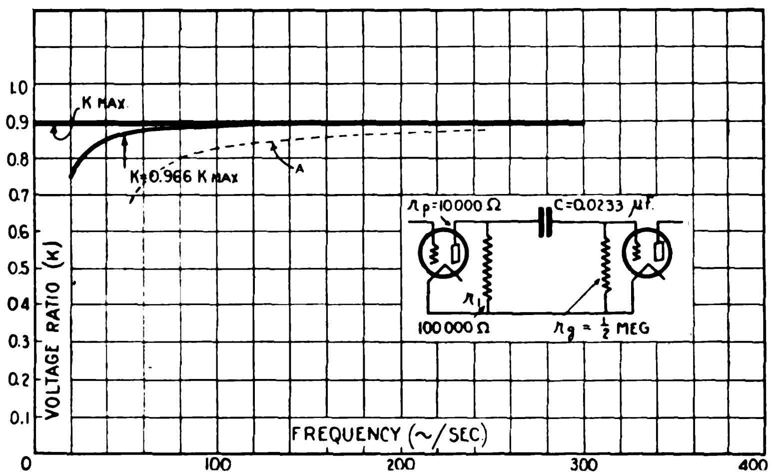

FIGURE 2

f_0, say 50 cycles per second, a certain fraction, k, of the maximum voltage ratio possible with the given combination of resistances.

The latter is the same as the voltage ratio at very high frequencies. Therefore:

$$k = \frac{K}{K_{max}} \tag{4}$$

Performing the operation indicated by (4), and solving for C,

$$C = \frac{(r_1 + r_p)}{2\pi f_o[r_g(r_1 + r_p) + r_1 r_p]\sqrt{\frac{1}{k^2} - 1}} \tag{5}$$

This equation has been plotted in Figure 4, for three different values of k. In the present problem the lower limit of the voltage

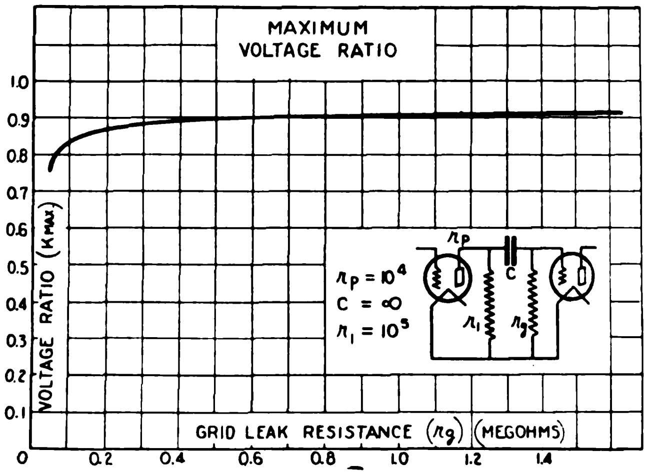

FIGURE 3

ratio is 90 per cent of the maximum attainable voltage ratio at the output of the amplifier. If there are two identical stages in the amplifier the value of k per stage will be $\sqrt{.90}$ (or 0.949); if there are three identical stages the value of k per stage will be $\sqrt[3]{.90}$ (or 0.966).

Figure 3 has been plotted for the purpose of noting what effect the grid-leak resistance has on the voltage ratio. For $r_p =$ 10,000 ohms, and $r_1 = 100{,}000$ ohms, it will be seen that little is gained in voltage ratio by making the grid-leak resistance greater than about 0.5 megohm. Applying this value to Figure 4, the capacity required in a three-stage amplifier in which the output voltage will not drop more than ten per cent from the high frequencies down to 50 cycles per second, is 0.0233 μf. These values were then used to calculate the curve of Figure 2.

The choice of r_g from Figure 3 depends not only upon the desired voltage ratio, but must also be sufficiently low that the grid does not accumulate an excessive grid charge. This matter is apart from the subject of this paper, but is to be considered in the design of the amplifier.

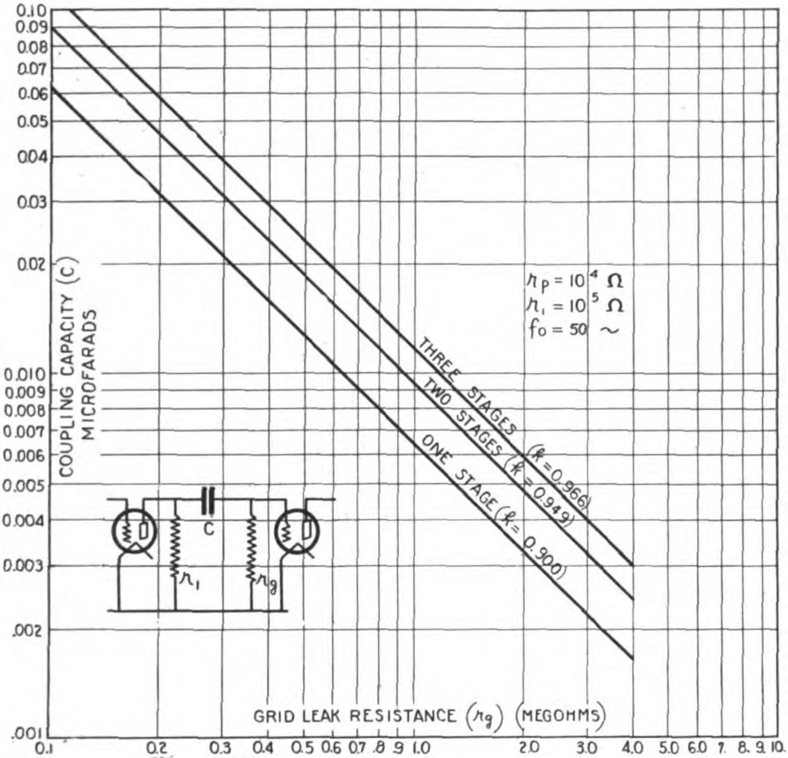

FIGURE 4

To illustrate the effect on the frequency characteristic of using too small a coupling condenser the curve marked "A" in Figure 2 was obtained experimentally, using the same resistances indicated on Figure 2, but a much smaller condenser.

SUMMARY: An analysis of the coupling in the resistance-capacity coupled amplifier is given, in which the variation of the voltage ratio with frequency is considered. A method is given for determining the values of the resistances and capacities for which the variation of voltage ratio over a given frequency range will be a definite and known amount.

SIMULTANEOUS ATMOSPHERIC DISTURBANCES IN RADIO TELEGRAPHY

By

M. Baumler

(Fourth Contribution from the Telegraphentechnischen Reichsamt.)

In three previous contributions on the appearance of simultaneous disturbances it was determined that the effect of a large part of the atmospheric disturbances extends not only over a small area around the receiving station, but that these same disturbances are noticeable at observation points at some distance from each other, and also that the range of the effect of the atmospheric disturbances is at times very large. The method of observation consisted of recording the atmospheric disturbances along with reference signals with recording apparatus in two places. The daily time signals from Lyon from 10 o'clock to 10.05 A. M. served as signals for determining simultaneous disturbances. The simultaneous or related disturbances can be determined from the occurrence of the disturbance relative to the simple mark of the time signals. The investigation led to the conclusion that between Gräfelfing, near Munich, and Strelitz—a distance of 580 km.—at which places the receiving apparatus was not influenced by local power disturbances, 98 per cent of all recorded disturbances occurred together. Between Berlin and Strelitz, as well as between Hamburg and Strelitz, the percentage of simultaneous disturbances was smaller, as in the large cities local power disturbances occur as well as the pure atmospheric disturbances. The extension of the experiments from Berlin to the east coast of North America—a distance of 6,400 km.—gives similar indications of simultaneous disturbances.

If one assumes the occurrence of disturbances at great distances as due to the propagation of electromagnetic waves, and that is a prevailing opinion of the nature of the atmospheric disturbances, it is left to try to determine whether disturbances at great distances do occur simultaneously and whether the percentage reaches any considerable amount.

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The continuation of the experiments was made possible through the cooperation of the Radio Corporation of America, which had already taken part in the earlier experiments. The receiving stations at Kokohead at Oahu Hawaiian Islands and Marshall, California, belonging to the Radio Corporation and a special experiment station of the Telegraphentechnischen Reichsamt at Berlin served as recorder stations. The signals were sent on a wavelength of 17,500 meters from the transmitting station at Rocky Point (WQL) according to the following plan:

Test de WQL Date
a . . . . b . . . . c . . . . d . . . . etc. to z
Test de WQL Date
aa . . . ab . . . ac . . . ad. etc. to az
Test de WQL Date
ba . . . bb . . . bc . . . bd . . . etc. to bz

The space between the two letters or groups of letters amounted to 5 centimeters on the transmitting tape, the transmitting speed being 30 words per minute. The transmitting plan proved to be very satisfactory.

The distance between the transmitting and receiving stations are:

Rocky Point—Berlin 6,400 km.
Rocky Point—Marshall 4,300 km.
Rocky Point—Kokohead 8,200 km.
Marshall—Kokohead 3,900 km.
Berlin-Rocky Point-Marshall 10,700 km.
Berlin-Rocky Point-Marshall-Kokohead 14,600 km.

The great circle distance from Berlin to Kokohead, azimuth 8 degrees west of north, amounted to 11,700 km. The ink recorder of the Radio Corporation was used in Kokohead and Marshall, and a recorder similar in construction to the siphon recorders in cable telegraphy furnished by Fa. C. Lorenz, A.G., was used in Berlin. The investigation was carried out from March 1 to March 28, 1925. The transmitting time was from 3.30-3.35 A. M. eastern standard time or 9.30-9.35 P. M. in Berlin, 12.30-12.35 A. M. in Marshall and 10.30-10.35 P. M. in Kokohead. During the investigation it was, therefore, daylight in Berlin—Sunrise in March being approximately 5.50-6.50 A. M.—and night in Rocky Point, Marshall and Kokohead. The tape of the receiving apparatus was adjusted to a velocity of 1.5 meters per minute. This was not always possible. Photographs of the

original tapes show how closely equal spacing of the characters on the various tapes was attained.

The quality of radio reception is dependent upon the ratio of signal strength to the atmospheric disturbances. If the ratio approaches unity, the possibility of recording decreases and reception is impossible if the signals fall below the disturbances or are otherwise suppressed, *i.e.*, if the average strength of the disturbance is higher than the signal strength. In the telephone receiver, disturbances of medium strength are noticeable through a continual grinding noise; in the recorder the pen moves back and forth across the tape tracing a non-readable curve. Such a case is shown in Figure 1, with a section of the tape taken March

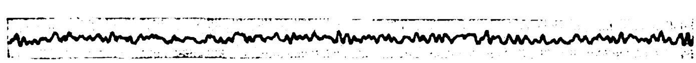


FIGURE 1—Kokohead, March 4, 1925

4, 1925, in which the signals of the transmitting scheme are in general unintelligible. Recording of signals from WQL at Kokohead is often impossible due to atmospheric disturbances, as the intensity is very different on various days. Also it must not be overlooked that the transmitting station at Rocky Point (WQL) is intended for traffic with Europe with distances of from 6,000 to 7,000 km., while the distance from Rocky Point to Kokohead is 8,200 km. with the greater part of the distance over land and hence unfavorable to the propagation of the electromagnetic waves.

We now turn to the results of the investigation. Figure 2 shows the section of the tape aj (- — - — — —) to ak (- — — - —) on March 27, 1925. The letters are somewhat

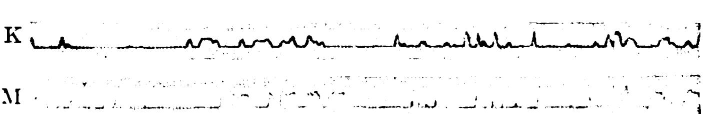


FIGURE 2—Kokohead and Marshall, March 27, 1925

mutilated in Kokohead but still recognizable. There is no doubt that the disturbance impulses obtained in Marshall are also present in Kokohead. In addition, a few other apparently purely local disturbances are observed in Kokohead.

Figure 3 show a section of the tape bg (— - - - — —.) to

bh (— --- ----) on March 14, 1925. The disturbances recorded in Marshall are also recorded in Kokohead. The simultaneity is easily seen by comparing the two tapes. The tape at Kokohead is an example of showing the effect of disturbances on

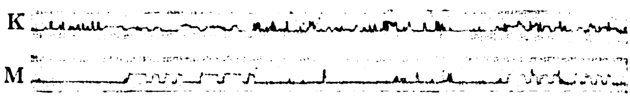


FIGURE 3—Kokohead and Marshall, March 14, 1925

the signals. The disturbances are even stronger than the signals. The reason for the smaller number of disturbances recorded at Marshall as compared to Kokohead is that the ratio of the signal to the strength of the disturbances was higher than in Kokohead and less amplification in the receiving apparatus necessary. The field strength at Marshall was higher, due to the shorter distance from Rocky Point.

Figures 4 and 5 show the tape sections x (—— — ——) to y (— - — ——) and ad (- — — - -) to ae (- — -) on March 10, 1925, at three receiving locations. The records of the signals and the disturbances are well shown. On the tape

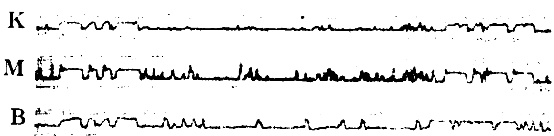


FIGURE 4—Kokohead, Marshall and Berlin, March 10, 1925

from Kokohead and Marshall individual groups of disturbances can be differentiated which consist of several single disturbances. It must be admitted that the disturbance groups and individual

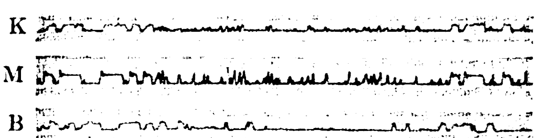


FIGURE 5—Kokohead, Marshall and Berlin, March 10, 1925

disturbances agree completely at the American receiving stations. The disturbances are less in Marshall as the signal amplitude

is greater than in Kokohead, so that here the weaker disturbances appear only as smaller deflections above the zero line. From a count of the common disturbances and the determination of the percentage, and even without going through these computations, it is seen that nearly all of the disturbances recorded occur together and are of the same origin. At first sight, no disturbances common to Berlin and both the American receiving stations are received even when one considers the time interval between the reception of a signal and a disturbance impulse which it is assumed is received first in Marshall. For a tape velocity of 150 centimeters in a minute this difference is about 2/3 mm. on the tape. The character of the disturbances in Berlin is apparently quite different from that in Kokohead and Marshall. On the Berlin tape only a few occasional disturbances are seen. If one observes the tape somewhat closer one sees that between the dot and the second dash of the letter y for Kokohead and Marshall (underlined in Figure 4), a disturbance is shown which is also seen to occur in Berlin, for at this place, the y is not clearly recorded but mutilated; also it appears that the strong disturbances directly before the y are common to Berlin and Marshall.

Figures 6 and 7 are sections of the tape from three receiving stations on March 18, 1925.

The tapes are placed alongside each other and one can see the last letters of the test announcement: "Test de WQL March eighteenth." The Morse characters are drawn in on the tape

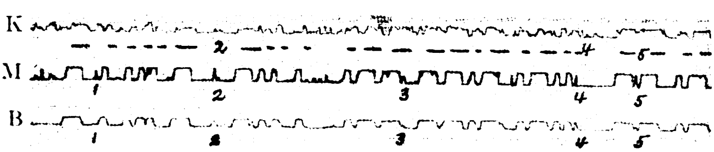


FIGURE 6—Kokohead, Marshall and Berlin, March 18, 1925

taken at Kokohead. The distribution of the disturbances is: few in Berlin, somewhat greater number in Marshall and a large number of disturbances in Kokohead. The signals in Kokohead are considerably mutilated by disturbances so that the text would be unintelligible if it were not known. On closer examination, a large part of the disturbances recorded in Marshall is found in the record at Kokohead, in spite of the great variation in the record. A comparison of the three tapes gives an agree-

ment of a few of the disturbances recorded in Berlin with those in Marshall and even with those in Kokohead. The disturbances occurring simultaneously are marked by means of numbers.

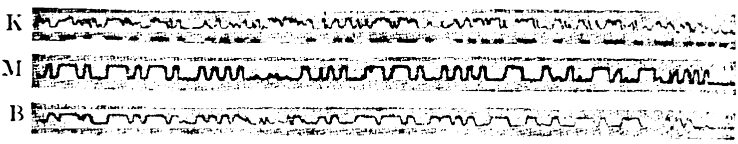


FIGURE 7—Kokohead, Marshall and Berlin, March 18, 1925

Between Berlin and Marshall the disturbances marked 1–8 correspond. On account of the small number of disturbances generally recorded this agreement should not be considered accidental. Between Berlin and Kokohead, an agreement is found in the disturbances marked 2, 4 and 5.

According to the present view, as previously mentioned, atmospheric disturbances consist of electromagnetic waves that have their origin in nature's electrical adjustments; one may speak, therefore, of these as natural waves in contrast with the waves artificially generated at a transmitting station. If we consider atmospheric disturbances as electromagnetic waves, then the laws of electromagnetic propagation must hold, that is, the propagation of disturbances must be better at night than during the day and the disturbances considerably reduced during the transition from darkness to daylight or vice versa, that is, in passing through a twilight zone. The relative location of the four receiving places with respect to day and night has been previously mentioned.

The explanation for the large number of simultaneous disturbances at Marshall and Kokohead lies in the good propagation conditions obtaining at night.

The extent to which disturbances occur simultaneously at different places depends further upon their strength, the distances of the observation points from the source and the sensitiveness of the receiving systems. If the disturbance is very strong, its effect may be felt at widely separated places. It is, however, not to be expected that the number of simultaneously occurring disturbances should reach any large amount and still less so if natural obstacles affect propagation. This accounts for the small number of disturbances common to Berlin and the American observation points. Correlation of the occurrence of

disturbances of same origin at still greater distances may be established when proper receiving apparatus is provided.

Sudden disturbances in the electrical field of the atmosphere, the magnetic field of the earth, displacements inside the earth and electrical adjustments in the cosmos may be the source of disturbances. To the variation in the earth's electrical field belong lightning discharges, most important being the strong lightning discharges in the tropics.

By our researches we have ascertained the distant effect of lightning discharges. All unobjectionable disturbances arising from visible discharges should be especially marked on the tape. During the investigation strong thunder storms were encountered in Kokohead whose effect on the receiving system was so strong that the observations had to be suspended to prevent harm to observers and damage to the apparatus.

The results of the investigation are summarized as follows:

A large number of disturbances occur simultaneously in Hawaiian Islands and California, 3,900 km. apart; occasional disturbances occur simultaneously at distances 10,000-12,000 km. apart. The general propagation phenomena of electromagnetic waves are applied to the propagation of disturbances and explain thereby the frequency of the simultaneous occurrence of disturbances.

It is the intention to continue the investigation and to select the conditions so that the observation points lie entirely in light or darkness.

I do not wish to close without heartily thanking the engineers of the Radio Corporation at the receiving stations at Kokohead and Marshall as well as at the transmitting stations at Rocky Point, and especially, Director A. N. Goldsmith, who through their willingness and cooperation made the investigation possible.

SIMPLIFIED S.L.F. AND S.L.W. DESIGN*

By

O. C. Roos

(Consulting Engineer)

A concise paper on the design of S.L.F. condenser plates appeared August, 1925, in the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, by Mr. H. C. Forbes. The method of attack is shown in Figure 1, where a polar curve 1-2-3-4-5 following a counter-clockwise or positive rotation, has a portion 3-4-5-3 of its polar area, used as a condenser plate. Its curved edge follows the polar equation

$$\rho^2 \theta^3 = K \tag{1}$$

The method of computing plate areas from the initial line o-z is the usual one, but is awkward, as it introduces the possibility of infinite plate areas and zero frequencies—both absurdities.

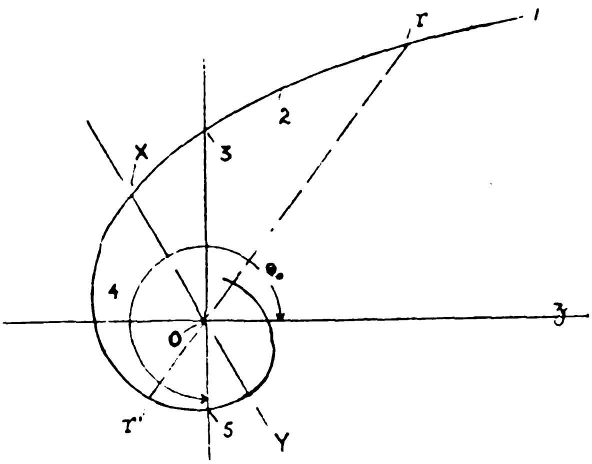


FIGURE 1

Again, the very beautiful simplicity of the law for predetermination of the frequency range as a ratio of f_m to f_n—maximum

*Received by the Editor, September 5, 1926.

and minimum frequencies respectively,—is overlooked and time is used in computation of a quantity that a simple ratio would give, if specified in advance.

For example, in Figure 1a we have a circular stator and a S.L.F. rotor plate. The latter has its straight edge 3-0-5 at right angles to the initial line o–z and its shortest radius at 0-5 makes an angle of 270 degrees with o–$\dot{z}$. In Forbes' notation

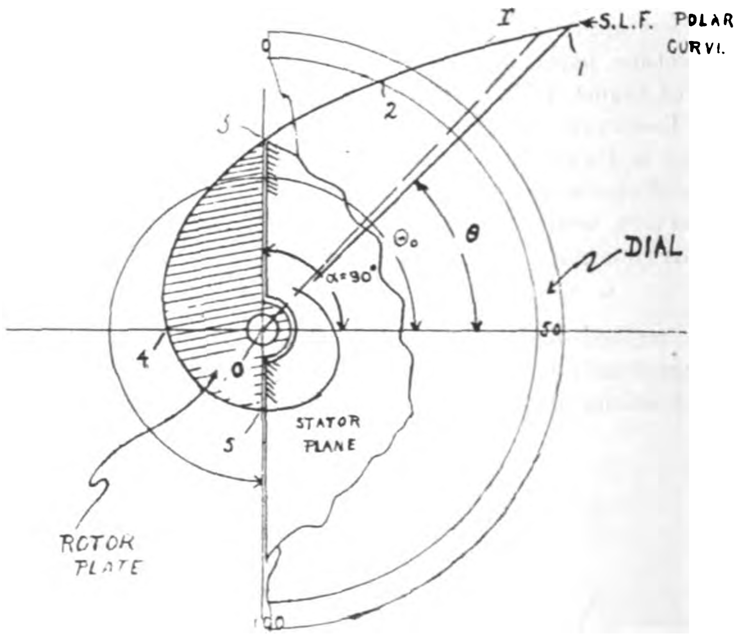


FIGURE 1a

this angle is θ and gives C_o or a zero capacitance, corresponding to stray capacitances which make up the polar area to infinity beyond his $\theta = 0$, which is really 270 deg. or $3\pi/2$. This fictitious area for outside capacitances C_o is A_o.

$$A_o = \frac{K}{\theta_o{}^2} = \frac{K}{\left(\frac{3\pi}{2}\right)^2} \tag{1.1}$$

and could have been used in place of C_o times a constant. The relationship between maximum and minimum plate areas and the longest radius in the plate polar curve would then have been apparent.

Forbes writes $$C_\theta = \frac{D^2}{(D/C_o - K\theta)^2} \tag{2}$$

and it is obvious that when we rotate the plates positively,—counter-clockwise—the effective capacitance C_o may become infinite. This equation means that the 270-degree angle through z–1–2–3–4–5 in Figure 1a, corresponding to minimum frequency D/C_o or f_n, is unlimited in polar area. Therefore, if it could be meshed to give capacitance with another such plate, the frequency would be zero. No mention is made of any limit of positive plate rotation, although this must be 180 degrees and in any case less than C_o or 270 degrees. The capacitance may therefore be increased without limit by positive rotation, to 270 degrees with this as the greatest theoretical rotation of dial.

The awkwardness of this point of view—*i.e.*, working from the initial line of the polar plate-area curve,—should be noted. Even though this initial area is infinite, it does not include the important capacitance C_o which is due to the stray and extra capacitances related to the condenser at its "zero" position. This zero capacitance C_o and its predetermination is the whole secret of a rigorously accurate S.L.F. or S.L.W. condenser and should preferably be in the form of a simple ratio of the final polar radius angle to the initial polar radius angle of the plate-curve area to be selected.

When the plates are completely meshed in Figure 1a the wave length is three times its value at the zero position. In Figure 2 let us imagine a symmetrical stator plate completely meshed

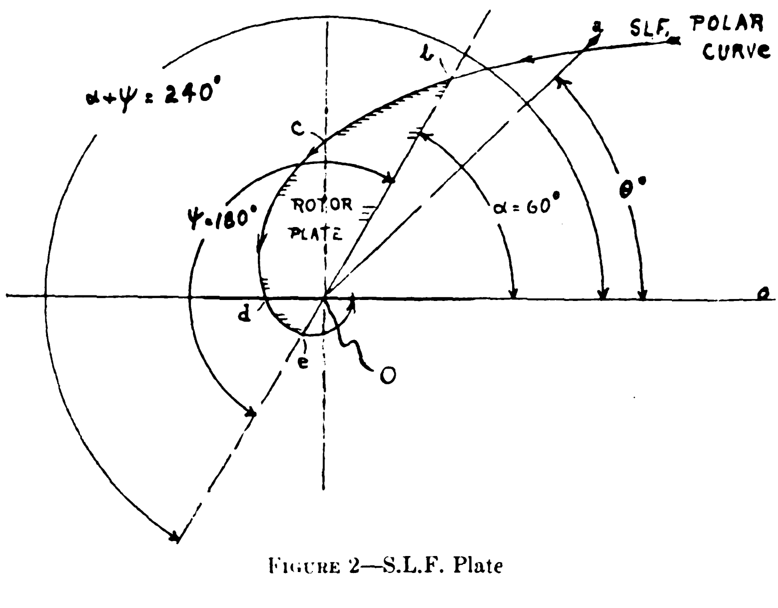


FIGURE 2—S.L.F. Plate

with the rotor b–c–d–e–b. Its edge coincides with the rotor plate edge e–o–b. Then the wave length is shortest and is four times that given by the fictitious area, C_o, beyond o–e and which is one-fifteenth of the total plate area meshed.

In all plate-area ratios the effective "area" added by the wiring and stray flux is present as a practically constant extra quantity, for all positions of the rotor. If the maximum capacitance C_o in Figure 1a is 513 $\mu.\mu.f.$ then the external or minimum capacitance C_o must always be kept at one-ninth of this or 57 $\mu.\mu.f.$

Most radio manufacturers have ignored this requirement. One cannot design S.L.F. or S.L.W. condensers accurately without adjustable verniers for a constant C_n. The writer has been able to do this systematically. The self-capacitance of the same type of coil varies 10 per cent in production, so an adjustable extra capacitance is absolutely imperative for accurate S.L.F. or S.L.W. characteristics.

Re-examining our rotor plate, we will find that of 513 $\mu.\mu.f.$ total capacitance, 8/9 or 456 $\mu.\mu.f.$ corresponds to the plate area, and the balance is the everpresent "zero" capacitance.

The question now is: since we can't use the infinite "plate area" in Figure 4, to the "right" of o–b, where can we find this "zero" capacitance area, corresponding to 57 $\mu.\mu.f.$

The answer is simple but has not yet been given in any paper. The polar area from o–e continued onward counter-clockwise forever—($\theta = \infty$)—is not infinite but finite. It is equal to C_n and

$$C_n = \frac{M}{(a+\psi)^2} = 57\ \mu.\mu.f.$$

Hence by integrating from o–b corresponding to $\theta = a$ to $\theta = a + \psi$ we have $C_n = \dfrac{M}{a^2} = 513\ \mu.\mu.f.$ or

$$C_m = \frac{M}{a^2} = 513\ \mu.\mu.f., \text{ or } C_m/C_n = 9.$$

Mr. Forbes explicitly defines C_o as that capacitance which is present in the circuit when θ, the variable angle from the initial plate position, is made equal to zero. The presence of an infinite value for one of his limiting capacitances, *i.e.* polar areas, indicates that he has integrated said area from the initial line O–o in Fig. 1a, counter-clockwise, instead of clockwise from the pole or what is the same thing, counter-clockwise from the

initial angle a of the polar area, in Figure 2, to infinity. In this way the polar area comes out for the condenser plates, as

$$A = \frac{K}{a^2} - \frac{K}{(a+\psi)^2} \tag{3}$$

Now the frequency is given by

$$f = \frac{1}{\sqrt{A_\theta}} = \frac{1}{\sqrt{C_\theta}} = m\,\theta \tag{4}$$

and equation (1.1) is satisfied. The usual allowances of $+r_o^2$ and $-r_o^2$ for stator cut-out and circular separators respectively, produce the normal equation

$$\rho = \sqrt{\frac{4K}{\theta^3} + r_o^2 - r_1^2} \tag{5}$$

The prediction of the ratio $\frac{\lambda_m}{\lambda_n}$ or g is rendered easy and accurate by the formula

$$a = \frac{\psi}{g-1} \tag{5.1}$$

where ψ is the angle of the rotor plates—usually 180 degrees—and a is the initial angle in Figure 1.

If $g = 2.5$—corresponding to $\lambda_m = 550$, $\lambda_n = 220$ meters—then $a = \frac{180}{1.5} = 120$ degrees. Hence the rotor plate would be out from the polar area along the line x–0–y, which is 120 degrees from O–0.

It is important to emphasize the fact that the area of the polar curve in the condenser plates is $\frac{g^2-1}{g^2}$ of the finite polar area from a to infinity, *i.e.*, if g is 3, then this plate area is 8/9 of the total finite polar area, the smaller or "zero" capacitance "area" being the "area" furnished by wires, tubes and stray flux. It should be noted that the polar curve defined by $\rho^2\theta^3 = K$ of Figures 1, 1a and 2 has no point of inflection.

By building up a S.L.W. plate-curve from the pole outward, just as we have done in the above S.L.F. plate-curve, we can make up a combined S.L.W. and S.L.F. plate. The S.L.F. plate has its lower frequencies crowded together on the initial dial divisions. The S.L.W. plate has its shorter waves similarly crowded together on the initial dial divisions.

By starting with 75 degrees on a S.L.W. plate for 1600 to 800 kc. and finishing up with 375 meters to 585 meters on a

S.L.F. plate, we avoid crowding along both S.L.W. and S.L.F. scales.

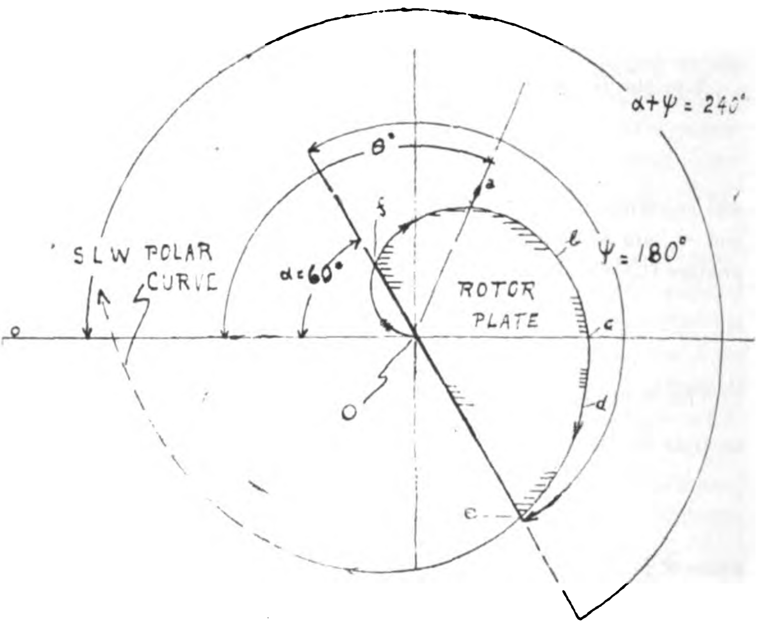


FIGURE 3—S.L.W. Plate

The S.L.W. plate is very easy to select from the S.L.W. polar curve shown in Figure 3. Unlike the S.L.F. curve, this S.L.W. polar curve starts exactly at the pole itself, when θ is

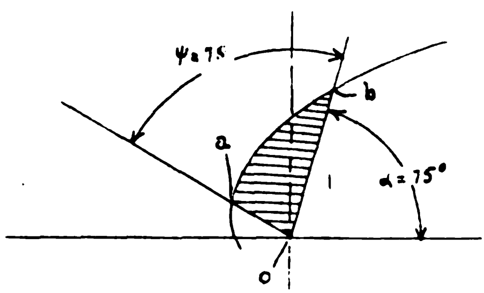


FIGURE 4—S.L.F. Plate Segment

zero. In a word, the radius is zero, in accordance with the equation

$$\rho^2 = 4\,K\,\theta$$

and the area, denoted by A, is given by

$$A = K\,\theta^2$$

The law of relative areas for S.L.W. ranges is the same in form as that for the S.L.F. type of plates, *i.e.* $a = \frac{\psi}{g-1}$ where ψ

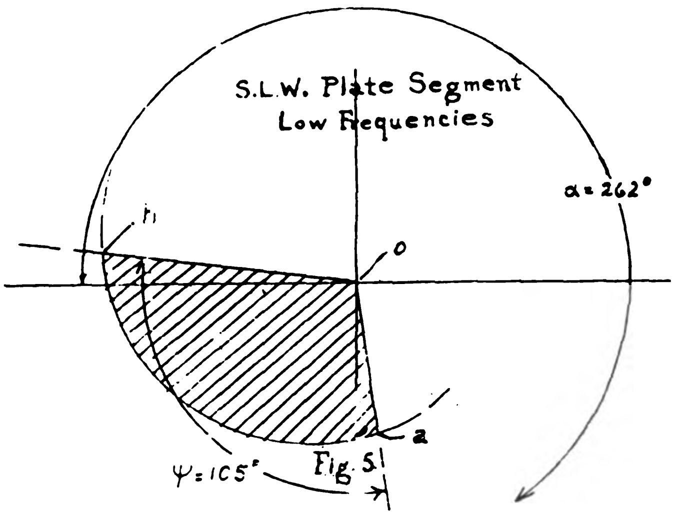


FIGURE 5

is the actual total plate rotation, g is the ratio of maximum to minimum wave length and a is the angle of the shortest polar radius vector used in Figure 3, corresponding to the shortest radio edge (in the S.L.F. plate it is the *longer* radial edge) of the condenser plate.

Working out these angles for the combined plate from

$$\rho^2 \theta^3 = K \text{ for S.L.F.}$$

and

$$\rho^2 = 4\,K'\,\theta \text{ for S.L.W.}$$

we find that the S.L.W. shortest edge is at 75 degrees from the initial line—see Figure 4,—and ends at 150 degrees from same. The last edge here and the first edge of the S.L.F. area must be

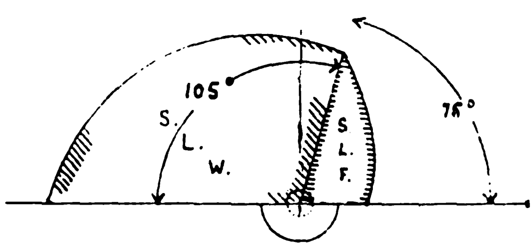


FIGURE 6—Combined S.L.F. and S.L.W. Plate Segments

the same in length, though the S.L.W. and S.L.F. curves need not be tangent to each other at this point, as some engineers seem to think.

The S.L.F. edge is started at 262 degrees and takes up 105 more degrees, ending at 367 degrees, as in Figure 5. Note that its longest radius at 367 degrees is the same as the shortest radius of the S.L.W. polar plate area.

The combined plate is sketched in Figure 6 and as we have two separate constants K and K', we have two degrees of mathematical freedom to make these edges as short or as long as necessary to coincide. No account is taken of cut-outs, for simplicity of illustration.

RADIO SIGNAL STRENGTH AND TEMPERATURE*

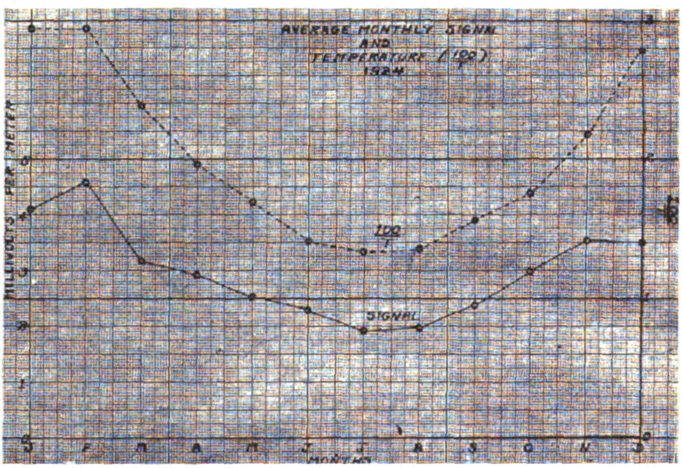
By

L. W. Austin and I. J. Wymore

(Laboratory for Special Radio Transmission Research)

(Conducted jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy)

During the cold waves of January, 1924, a marked increase in the strength of the signals from the transatlantic radio stations at Tuckerton and New Brunswick, N. J. was observed at Washington.[1] This was considered remarkable as the commonly accepted ideas regarding the earth's atmosphere indicate that there should be no connection between the weather near the ground and conditions at a height of 100 km., or more, where the main variations in signal intensity are supposed to be produced.



Transmission from stations at moderate distances, 200 to 600 km., seems better fitted for the study of possible meteorological influences than that from distant stations; for, while the relative

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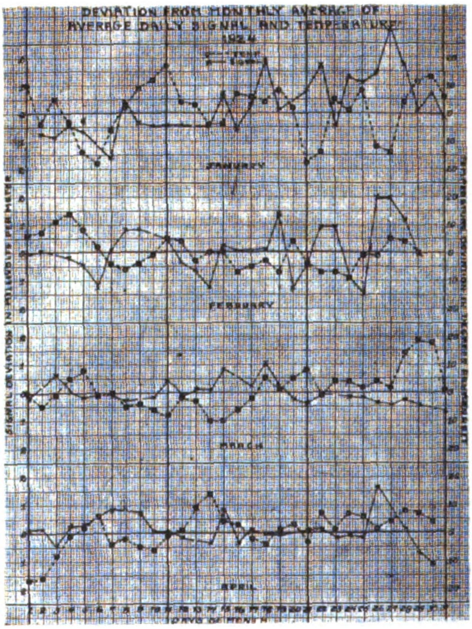
*Published by permission of the Director of the National Bureau of Standards of the United States Department of Commerce.

[1] Proceedings of The Institute of Radio Engineers, vol. 12, p. 681; 1924.

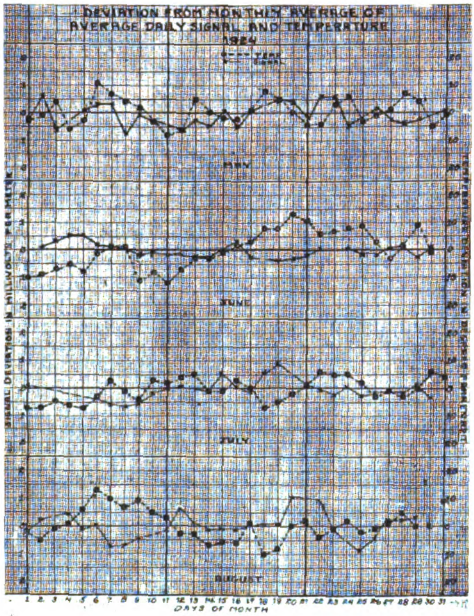
variations in signal field intensity are approximately the same, in the latter case weather conditions can not be expected to be uniform over the whole signal path. For distances much less than 200 km., the variations in signal strength for ths usual trans-atlantic wave lengths may become too small for profitable study.

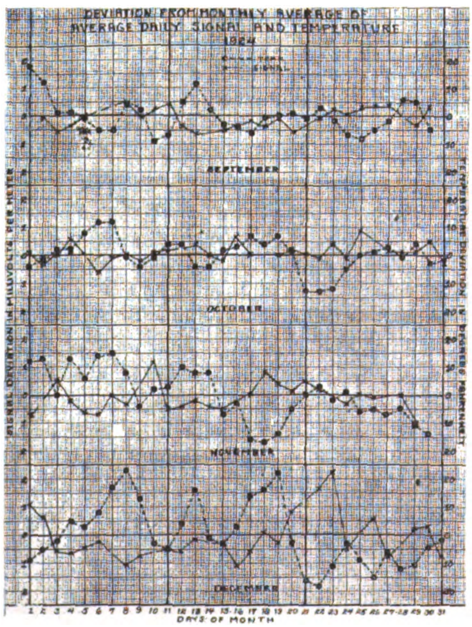
Continued daily observations on the two stations, extending over more than two years appear to prove that there is some kind of inverse relationship between signal strength and local temperature, though this temperature effect is often masked by other influences.



The degree of temperature—signal relationship may be judged from the accompanying curves for the year 1924. In the curve of monthly averages for the year, the average daylight signal intensity of the two stations corrected for antenna current changes is shown in millivolts per meter with the corresponding curve of 100/temp. (F.). The curves of daily averages for each month represent the plus and minus deviations of the signal intensity and of the temperature from the monthly means.

In the case of the curve of monthly averages, the connection between signal and temperature is self evident, the average signals of February being more than twice as strong as those of


DEVIATION FROM MONTHLY AVERAGE OF
AVERAGE DAILY SIGNAL AND TEMPERATURE
1924
MAY
JUNE
JULY
AUGUST
DAYS OF MONTH


DEVIATION FROM MONTHLY AVERAGE OF
AVERAGE DAILY SIGNAL AND TEMPERATURE
1924
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
DAYS OF MONTH

July and considerably stronger than would be required by the inverse distance law (3.52 millivolts per meter). The day-by-day relationship is less satisfactory, varying from fairly clear in the winter months to obscure in midsummer.

That the variations in signal strength are actually produced in the upper atmosphere and not in the portion of the wave traveling along the ground seems to be proved by the fact that in the region involved there is no definite change in signal intensity, due to long continued rains or droughts or to the presence or absence of snow, for wave lengths over 1,000 m.[2] In addition, it is hardly conceivable that the rapid intensity changes observed during cold waves could be due to the penetration of frost in the ground, which is of necessity a gradual process.

	Frequency	Wave Length	Antenna Current	Effective Height	Distance
New Brunswick...	22.1 kc.	13,600 m.	600 amp.*	66 m.	281 km.
Tuckerton........	18.9 kc.	15,900 m.	500 amp.	68 m.	251 km.

*All observations are reduced to 600 amperes antenna current for New Brunswick and 500 amperes for Tuckerton.

[2] See PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, vol. 3, p. 310; 1915.

PREFERRED NUMBERS

By

L. A. Hazeltine

Among the many projects in standardization that are being considered by the American Engineering Standards Committee is one with a very wide field of application and of interest to all classes of engineers. This is the use of so-called Preferred Numbers. Such numbers are applicable particularly in the rating of apparatus where the values are initially arbitrary, where the range in values is wide, and where a geometrical series is not precluded by special technical considerations. The rating of motors is an example. A one-horsepower motor is in common commercial use, not because there is naturally more demand for 1 h.p. than for 0.9 or 1.1 h.p., but because the number 1 is a round number. The next larger size might be 1.5 h.p. or 2 h.p., depending on the size of step required by commercial considerations, rather than such odd numbers as 1.45 or 2.1 respectively.

Now the system of preferred numbers that has been most favored is one having the following properties: The numbers are very closely in a geometrical series; they include the number and factor 10, so that the series can be indefinitely extended by factors which are powers of 10; they include a large portion of the "roundest" possible numbers—that is, single-digit whole numbers; they include the number and factor 2; and from the principal series, other series can be derived to give finer or coarser steps. The principal series is given in column 1 of Table I. For a coarser series, every other number may be omitted as in column 2, and for a finer series, geometric mean numbers may be interpolated as in column 3.

These series, with minor modifications, have been accepted in some European countries, conspicuously France and Germany. They are regarded as affording an underlying basis for the rational selection of sizes; and while not always adhered to on account of practical considerations, are given study as a possible solution, followed through in principle or in detail, in so far as conditions seem to permit. At the time of the recent meeting in New York of the International Electrotechnical

Commission, an informal conference was held in which several foreign engineers recounted their experiences with Preferred Numbers, and the consensus of opinion was quite favorable toward their extended use.

TABLE I

1	2	3
1	1	1
		1.12
1.25		1.25
		1.4
1.6	1.6	1.6
		1.8
2		2
		2.25
2.5	2.5	2.5
		2.8
3.2		3.2
		3.6
4	4	4
		4.5
5		5
		5.6
6.4	6.4	6.4
		7.2
8		8
		9
10	10	10
		11.2
12.5		12.5
		14
16	16	16

Possible applications of preferred numbers in the radio field would be in the capacity ratings of fixed condensers and in the resistance ratings of fixed resistors. It would seem that the values given in Table II, which covers only a limited range, would well fill commercial requirements and would be sufficiently

TABLE II

Fixed Condensers, Capacity in Microfarads.	Grid Leaks. Resistance in Megohms.
0.00025	0.25
0.0004	0.4
0.00064	0.64
0.001	1
0.0016	1.6
0.0025	2.5
0.004	4
0.0064	6.4
0.01	10

near the values of present practice to impose no hardship. Many other uses in radio, are, of course, apparent.

The Institute of Radio Engineers is taking part in the study of Preferred Numbers and their application, being represented on the A. E. S. C. Sectional Committee by the writer. Comments by radio engineers would be most welcome. The American Engineering Standards Committee has available a number of publications on the subject, which may be obtained by those interested, on request addressed to its headquarters at 29 West 39th Street, New York City.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued September 7, 1926 October 26, 1926

By

JOHN B. BRADY

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,598,630—A. M. WENGEL, Madison, Wisconsin. Filed June 6, 1922, issued September 7, 1926.

ELECTROTHERAPEUTIC APPARATUS for operation from the usual 110-volt, 60-cycle current with an oscillatory circuit connected to a spark-gap system which is excited from a step-up transformer.

1,598,663—J. S. STONE, San Diego, California. Filed November 31, 1920, issued September 7, 1926. Assigned to American Telephone and Telegraph Company.

MULTIPLEX RADIO TELEGRAPHY AND TELEPHONY, in which a plurality of pairs of balanced transmitting antennas and a plurality of pairs of balanced receiving antennas are provided, each transmitting pair being conjugate with each receiving pair.

1,598,848—C. C. CHAPMAN, Palo Alto, California. Filed March 24, 1923, issued September 7, 1926. Assigned to Federal Telegraph Company.

RADIO FREQUENCY ARC CONVERTER AND METHOD OF OPERATING SAME. An arc converter is illustrated having a gaseous atmosphere supplied to the arc chamber. The gaseous atmosphere contains hydro-carbon material and an auxiliary heater is provided for decomposing the hydro-carbon and altering the molecular structure of the material.

1,599,453—H. A. AFFEL, Brooklyn, New York. Filed June 24, 1922, issued September 14, 1926. Assigned to American Telephone and Telegraph Company.

ANTENNA STRUCTURE, for operation with a plurality of different wave lengths where a plurality of filters each having different frequency cut off points are connected between the terminating point of the antenna and an outer end thereof, the distance between each of the filters and the terminating point of the antenna being the optimum length of the antenna for the frequency at which the particular filter cuts off.

1,599,471—R. F. KENYON, San Francisco, California. Filed March 7, 1925, issued September 14, 1926.

RADIO RECEIVER, in which a crystal detector is mounted upon a vertical panel and a rock lever provided for permitting the searching of the surface of the crystal.

1,599,586—E. S. PURINGTON, Cambridge, Massachusetts. Filed April 27, 1922, issued September 14, 1926. Assigned to John Hays Hammond, Jr.

RADIANT SIGNALING SYSTEM, whereby a semi-secret method of broadcasting is provided. Oscillations are produced of substantially constant amplitude and then the frequency wobbled and the signals transmitted by alternately impressing signaling current in the wobbled or unwobbled condition in the transmission circuit.

*Received by the Editor November 22, 1926.

[illegible] T. SPOONER, Edgewood Park, Pennsylvania. Filed February 24, 1921, issued September 14, 1926. Assigned to Westinghouse Electric and Manufacturing Company.

PARALLEL OPERATION OF ARC OSCILLATORS, for obtaining a high alternating current from a direct current source of low voltage. Choke coils are included in the direct current leads to the arcs to prevent direct circuiting of the oscillating current and there is a ballast resistor individual to each of the arcs.

[illegible] H. W. DAVIS, Cleveland Heights, Ohio. Filed March 18, 1922, issued September 14, 1926.

RADIO RECEIVING UNIT, consisting of a support for an electron tube, a control rheostat and a jack for providing connections to a telephone headset.

[illegible] A. TOELLE, Anderson, Indiana. Filed October 13, 1922, issued September 14, 1926. Assigned to General Motors Corporation.

CONDENSER of coiled strip formation where the strips are wound in the shape of a cylinder and the cylinder supported from opposite ends, which provide terminals for the condenser.

1,599,959 C. E. WILSON and H. E. NORVIEL, Anderson, Indiana. Filed July 24, 1922, issued September 14, 1926. Assigned to General Motors Corporation.

CONDENSER of rolled paper and conductive strip construction formed in a compact cylinder body.

1,599,960 G. F. GILCRIST, San Francisco, California. Filed April 27, 1925, issued September 14, 1926.

PORTABLE FOLDABLE RADIO ANTENNA, consisting of wire frames which may be opened to cover a relatively large area or folded into compact size.

1,600,060 H. J. NOLTE, Schenectady, New York. Filed September 18, 1923, issued September 14, 1926. Assigned to General Electric Company.

ELECTRON DISCHARGE DEVICE of high power, wherein the grid is formed in a coil supported upon a frame carried from a ring which is bent around a plurality of supporting arms for providing a rigid mounting for the electrode.

1,600,115 L. D. KIMMEL, Bluffton, Ohio. Filed May, 26, 1923, issued September 14, 1926.

MILLED POST CONSTRUCTION FOR VARIABLE CONDENSER where a hexagonal post is milled to receive the edge of a condenser plate

1,600,204 E. F. W. ALEXANDERSON, Schenectady, New York. Filed November 28, 1924, issued September 14, 1926. Assigned to General Electric Company.

MEANS FOR TRANSMITTING ANGULAR MOTION, where impulses are radiated and the time-period thereof varied in accordance with the position of a transmitting device in such manner that a receiving device is enabled to reproduce the movements of a motion transmitting device.

1,600,421 J. MILLS, Wyoming, New Jersey. Filed December 28, 1920, issued September 21, 1926. Assigned to Western Electric Company.

OSCILLATION CIRCUIT having a high degree of constancy. The circut is enclosed in an envelope where the pressure is maintained low compared to that of the atmosphere for avoiding changes in frequency, due to changes in temperature.

1,601,065—T. R. GRIFFITH, Dover, New Jersey. Filed October 5, 1920, issued September 28, 1926. Assigned to Western Electric Company.

ELECTRON DISCHARGE DEVICE, in which the cathode is centrally positioned with respect to the cathode and grid and water-cooled by an eternal supply of water to the tube.

1,601,066—J. E. HARRIS, Newark, New Jersey. Filed Dcember 8, 1922, issued September 28, 1926. Assigned to Western Electric Company.

ELECTRIC DISCHARGE DEVICE, in which a cathode is provided, composed of barium and strontium oxides and an oxidized nickel chromium alloy grid.

1,601,070—J. W. HORTON, East Orange, New Jersey. Filed April 18, 1922, issued September 28, 1926. Assigned to Western Electric Company.

WAVE METER, comprising resonant circuits for attenuating the current supplied thereto by different amounts and an indicator. Currents are supplied to the indicator in opposite direction and by controlling the resonant circuits the effective currents supplied to the indicator may be measured, which is proportional to the indication of wave length.

1,601,071 J. W. HORTON, Bloomfield, New Jersey. Filed April 18, 1922, issued September 28, 1926. Assigned to Western Electric Company.

OSCILLATION GENERATOR, in which tubes are coupled in feedback relation and the entire oscillating output energy delivered through a path adapted to limit at a predetermined value the amplitude of the oscillator current. Oscillations of a selected frequency are produced by the current transversing this path and the potential of selected frequency may then be impressed upon the control element of one of the tubes of the system.

1,601,075 A. W. KISPAUGH, East Orange, New Jersey. Filed April 10, 1924, issued September 28, 1926. Assigned to Western Electric Company.

SYSTEM OF SPACE DISCHARGE DEVICES, in which energy is supplied to the electrodes of the tubes in proper sequence and its applications controlled to prevent surges in the circuit of the system.

1,601,109 E. L. CHAFFEE, Belmont, Massachusetts. Filed March 31, 1922, issued September 28, 1926. Assigned to John Hays Hammond, Jr.

MULTI FREQUENCY RESONANT NET WORK, in which oscillations at different frequencies are impressed upon a net work which comprises reversely arranged couplings for preventing current impulses of one of the frequencies from reacting upon the source of the impulses of the other of the frequencies with means operatively connected with the net work for impressing the energy upon the ether for transmission of signals.

1,601,281 K. J. G. AHLSTRAND, Stockholm, Sweden. Filed May 4, 1926, issued September 28, 1926.

VARIABLE CONDENSER FOR TUNING ELECTRIC OSCILLATING CIRCUITS, in which a hollow spindle is provided with an auxiliary shaft thereon for securing a fine variation in the capacity of the condenser independent of larger variation under action of the main plates.

1,601,300 L. DIAMOND, Oakland, California. Filed July 27, 1925, issued September 28, 1926.

HELICAL PLATE CONDENSER, wherein the special relation of the plates may be varied by axial movement of a condenser shaft.

1,601,313 M. LATOUR, Paris, France. Filed August 19, 1921, issued September 28, 1926. Assigned to Latour Corporation.

VACUUM TUBE RELAY, where a direct current generator is arranged to charge a battery, which in turn delivers energy to the circuits of an electron tube.

1,601,322 A. PRESS, Wilkinsburg, Pennsylvania. Filed July 30, 1920, issued September 28, 1926. Assigned to Westinghouse Electric and Manufacturing Company.

DUPLEX RADIOTELEPHONY, in which the transmitting and receiving apparatus is alternately effective during spaced time intervals and so arranged that intermediate such intervals the transmitting apparatus does not interfere with the local receiving apparatus.

1,601,343 O. BUCHHOLZ, Neiderschonhausen, near Berlin, Germany. Filed August 26, 1921, issued September 28, 1926. Assigned to Westinghouse Electric and Manufacturing Company.

WAVE SIGNALING SYSTEM, in which a ground connection may be established between the grid circuit of one of the tubes of a cascade amplifier while such ground connection is prevented with the grid circuits of others of the tubes constituting the amplifier.

1,601,914 J. H. HAMMOND, JR., Gloucester, Massachusetts. Filed December 27, 1916, renewed May 17, 1923, issued October 5, 1926.

SYSTEM OF CONTROL BY LIGHT WAVES, in which a beam of sodium light is transmitted and received by a light sensitive element for actuating a responsive device. The receiving apparatus absorbs a specific spectrum of the light. The mass of material which receives the specific spectrum is rendered periodically effective and ineffective with respect to the indicating device.

1,602,056 PAUL M. TEBBS, Harrisburg, Pennsylvania. Filed December 1, 1924, issued October 5, 1926.

TUBE BASE, in which a tube is provided with side contacting members for establishing connection with radially directed contact members carried by the socket.

1,602,085 C. W. RICE and E. W. KELLOGG, Schenectady, New York. Filed April 10, 1920, issued October 5, 1926. Assigned to General Electric Company.

RADIO RECEIVING SYSTEM, comprising a substantially horizontal directive receiving antenna grounded at both ends with a physical length of at least the order of magnitude of the half wave length of the signaling wave to be received. The reflection of waves along the antenna is prevented and the receiving energy impressed upon the signaling receiving circuit.

1,602,086 C. W. RICE and E. W. KELLOGG, Schenectady, New York. Filed July 15, 1921, issued October 5, 1926. Assigned to General Electric Company.

RADIO RECEIVING SYSTEM, having highly directional characteristics. A low horizontal antenna is provided in which sets of series inductances and capacities are so proportioned that current waves of one particular frequency will be propagated along the length of antenna at a velocity substantially equal to the velocity of light.

1,602,198 M. LATOUR, Paris, France. Filed July 15, 1920, issued October 5, 1926. Assigned to Latour Corporation.

AERIAL FOR RADIO TELEGRAPHY AND TELEPHONY, having a plurality of ground connections with an electrically coupled system connected to the antenna for effecting a predetermined current flow in the ground connections for a given impressed transmitting current.

1,602,201 C. E. PEARSON, Cleveland, Ohio. Filed March 1, 1923, issued October 5, 1926. Assigned to The Teagle Company.

ELECTRICAL CONDENSER, where a plurality of conductive and dielectric sheets are secured under pressure by a resilient metallic clamping sheet which extends over the entire condenser.

1,598,824—P. E. KLOPSTEG, Chicago, Ill. Filed December 6, 1924, issued September 7, 1926. Assigned to Central Scientific Company.

AERIAL FOR RADIO RECEPTION, consisting of a foldable device having a hub with removable arms disposed in said hub. The arms of the frame are odd in number and carry a plurality of loops in staggered relation at each side of the frame.

1,599,104—A. H. TAYLOR, Washington, D. C. Filed May 29, 1923, issued September 7, 1926. Assigned to Wired Radio, Inc.

THERMIONIC VACUUM TUBE CIRCUITS, for transmission where the tube circuits are provided with means for compensating for variations in the supply of energy from the source to the circuits of the tubes during the making of signals.

1,599,180—O. T. McILVAINE, East Cleveland, Ohio. Filed July 2, 1925, issued September 7, 1926. Assigned to The Radio Television Company.

THERMIONIC TUBE, having an electron emitting member heated by a removable electric resistance unit which may be operated from the lighting circuit.

1,602,439—M. LATOUR, Paris, France. Filed (original) July 15, 1920; division filed October 30, 1923; issued October 12, 1926.

ELECTROMAGNETIC WAVE GENERATING SYSTEM, in which an oscillation generator has its output controlled by a tube which is placed in series with the grid filament circuit of the oscillator.

1,602,566—K. BURK, Basel, Switzerland. Filed January 6, 1925, issued October 12, 1926.

FRAME AERIAL FOR RADIO TELEGRAPHY AND TELEPHONY, which may be folded into a compact space. Wire is wound upon a series of spools which are carried by a frame, the wire being formed into polygonal shapes with minimum distributed capacity.

1,602,917—L. O. MARSTELLER, Wilkinsburg, Pennsylvania. Filed August 22, 1922, issued October 12, 1926. Assigned to Westinghouse Electric and Manufacturing Company.

RADIO RECEIVING APPARATUS, of compact size in which the receiving apparatus is contained within a small casing and switching equipment provided on the exterior of the casing for establishing connection with the apparatus interior thereof.

1,602,943—KARL ROTTGARDT, Dahlem, Germany. Filed August 26, 1921, issued October 12, 1926. Assigned to Westinghouse Electric and Manufacturing Company.

ELECTRICAL DISCHARGE VESSEL FOR THE PRODUCTION OF AMPLIFICATION OF OSCILLATIONS, in which a plate electrode and two grid electrodes one on each side of the plate electrode are provided. There is a direct metallic connection between the grid electrodes so that the grid electrodes are maintained at the same potential.

1,602,975—PAUL M. HENGSTENBERG, Wilkinsburg, Pennsylvania. Filed September 16, 1922, issued October 12, 1926. Assigned to Westinghouse Electric and Manufacturing Company.

RADIO RECEIVING APPARATUS, comprising a compact assembly of apparatus in which inductance coils within a casing are connected to an exterior switching apparatus. The supports for the casing also provide connections for the inductances interior of the casing.

1,603,041—R. GAUDIO, Brooklyn, New York. Filed February 18, 1926, issued October 12, 1926.

VARIABLE CONDENSER, comprising a pair of flat annular discs embedded in insulation material, one plate being movable with respect to an adjacent plate for varying the mutual capacity.

1,603,156—FRANK SEELAU, Detroit, Michigan. Filed October 23, 1924, issued October 12, 1926.

VARIABLE CONDENSER, consisting of flexibly mounted plates movable within a casing with a rotatable device for varying the spacial relation between the plates and the casing.

1,603,184—J. J. AURYNGER, Brooklyn, New York. Filed August 16, 1922, issued October 12, 1926.

CONDENSER, in which the plates are provided with a plurality of perferations having equal electric density throughout with a distributed unit area of plate capacity.

1,603,209—J. H. PAYNE, JR., Ballston Spa, New York. Filed September 30, 1922, issued October 12, 1926. Assigned to General Electric Company.

ELECTRICAL DISCHARGE DEVICE for high power operation consisting of a metallic casing with an electrode supported in the casing and a seal including a vitreous sleeve with a flexible member connecting the electrode and the seal.

1,603,284—J. B. JOHNSON, Elmhurst, New York. Filed November 24, 1924, issued October 19, 1926. Assigned to Western Electric Company.

ELECTRIC DISCHARGE DEVICE, having a fluorescent screen comprising a mixture of zinc salt and calcium tungstate.

1,603,369—T. WHEELER, Chicago, Illinois. Filed May 8, 1924, issued October 19, 1926.

LOOP AERIAL AND THE LIKE, which may be folded into a small compact structure for portable use. The cross arms are each arranged to support the wires in spaced relation at the extremities thereof.

1,603,468 -BERLIN-FRIEDENAU, Germany. Filed October 19, 1922, issued October 19, 1926. Assigned to Siemens and Halske.

METHOD OF IMPROVING THE INSULATION OF VACUUM TUBES, by providing an outwardly opening concavity whose walls consist of the same material as that which constitutes the tube. The outer opening of the cavity is closed by means of a non-hydroscopic insulator.

1,603,494—E. S. PRIDHAM and P. L. JENSEN, of Oakland, California. Filed November 8, 1924, issued October 19, 1926. Assigned to The Magnavox Company.

RADIO RECEIVING APPARATUS, in which a plurality of variometers are journaled on separate shafts and connected together by gearing for simultaneous control from a central point.

1,603,582—L. M. CLEMENT, Mountain Lake, New Jersey. Filed May 3, 1921, issued October 19, 1926. Assigned to Western Electric Company.

CARRIER WAVE TRANSMISSION SYSTEM, in which radio toll links are provided for connecting ordinary telephone and telegraph systems for two-way communication. The abrupt switching required in establishing radio toll connections introduces the problem of undesirable surges in the transmitter oscillator, and the invention is directed to circuits for avoiding these difficulties.

1,603,640—WALTER C. REED, Dalton, Massachusetts. Filed May 20, 1925, issued October 19, 1926. Assigned to Radio Products and Specialty Company.

RADIO FIXED CONDENSER, where a central eyelet rivet is provided for holding a plurality of concentric plates under pressure.

1,603,939—W. DUBILIER, New York, N. Y. Filed January 21, 1921, issued October 19, 1926. Assigned to Dubilier Condenser and Radio Corporation.

CONDENSER CONSTRUCTION for fixed electrical condensers wherein high insulation is afforded by the arrangement of a plurality of condenser sections into stacks which are separated from each other by dielectric sheets.

1,604,129—A. MEISSNER, Berlin, Germany. Filed August 8, 1922, issued October 26, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

TRANSMITTING ARRANGEMENT FOR RADIO TELEGRAPHY AND TELEPHONY, in which a plurality of separate paths are provided at different areas of the antenna. These areas are positioned at successively increasing distances from the apparatus and the paths have equal impedances.

1,604,140—H. A. AFFEL, Maplewood, New Jersey. Filed September 19, 1924, issued October 26, 1926. Assigned to American Telephone and Telegraph Company.

MULTIFREQUENCY OSCILLATOR, having a closed path in which the oscillations flow with circuits for determining a primary frequency and tuned circuits for providing a plurality of changes in frequency as the energy flows over the path. The frequencies which result from such frequency changes are not related to the primary frequency as harmonics thereof where an antenna is provided with separate paths connecting the apparatus with different areas of the antenna. These areas are at successively increasing distances from the apparatus and the paths have equal impedances.

1,604,171—C. B. KINLEY, Detroit, Michigan. Filed June 23, 1925, issued October 26, 1926.

CONDENSER OPERATING DEVICE, in which a slidable rack is arranged to operate a plurality of pinions for reciprocating sets of condenser plates with respect to other sets of condenser plates for controlling the tuning of a plurality of circuits.

1,604,403—JOHN H. FLYNN, JR., Cincinnati, Ohio. Filed December 15, 1924, issued October 26, 1926.

RADIO APPARATUS, in which a crystal detector is provided having a reciprocatory contacting arm which may be adjusted in position to select a sensitive point on the crystal.

1,604,508—ZISCH, G. J., West Orange, New Jersey. Filed March 25, 1925, issued October 26, 1926.

VERNIER CONDENSER of the variable plate construction where the sets of plates consist of sectors having progerssively differing areas.

1,604,533—RYAN, C. P., East Molesey, England. Filed February 26, 1924, issued October 26, 1926. Assigned to Vickers Limited.

RADIO CONTROL APPARATUS, which is tuned to the tone frequency of the signals and selectively actuated by incoming signals for closing a local control circuit.

D-71,138—FREDERICK DIETRICH, New York City, N. Y. Filed June 28, 1926, issued September 28, 1926. Assigned to Brandes Laboratories, Incorporated.

TABLE CONE DESIGN as manufactured by Brandes Products Corporation comprising an acoustic chamber and cone with a parabolic sound reflecting chamber enclosing the cone.

1,604,017—C. A. BRIGHAM and D. H. MOSS of Newark, New Jersey. Filed October 2, 1925, issued October 19, 1926. Assigned to Brandes Laboratories, Incorporated.

CONE TYPE LOUD SPEAKER, where the cone diaphragm is mounted within an acoustic chamber such as the cabinet of a radio receiver, and the sound reproduction modified by the operation of the cabinet.

1,600,980—WILLIAM H. GERNS, of East Orange, New Jersey. Filed December 11, 1925, issued September 28, 1926. Assigned to Brandes Laboratories, Incorporated.

SOUND REPRODUCER, consisting of an electro-magnetic operating mechanism having a screw threaded casing which may be adjusted to selected positions with respect to a sound-reproducing diaphragm for fixing the magnetic gap for efficient operation for particular programs.

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PROCEEDINGS
of
The Institute of Radio Engineers

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

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GENERAL INFORMATION AND SUBSCRIPTION RATES ON PAGE 1

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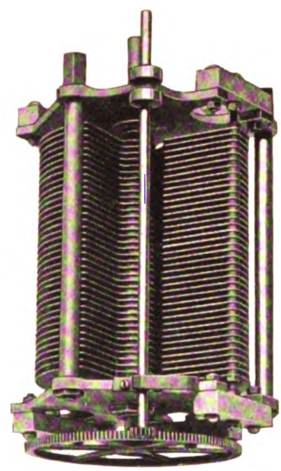
246
LABORATORY CONDENSER



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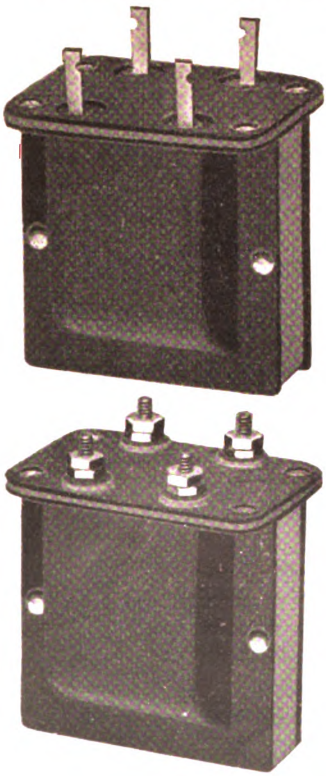

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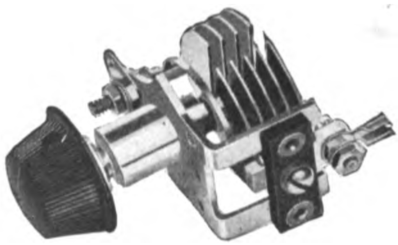

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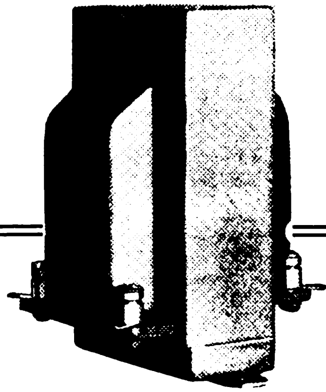

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July 26, 1926

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When it comes to dx ESCO sure is the berries. The information on filters that you gave me several months ago,was highly acceptable,and no doubt accounts for some of my good dx this summer.

My signals have been heard and worked in every part of the globe in the last two months of summer and I credit it all to the keen note the ESCO generator puts out. My filter system is what you suggested, namely, 30 henry choke,and 6 mfd condensers.

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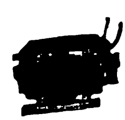

300 South St. — Stamford, Conn.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued September 7, 1926—October 26, 1926

By

JOHN B. BRADY

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,598,630—A. M. WENGEL, Madison, Wisconsin. Filed June 6, 1922, issued September 7, 1926.

ELECTROTHERAPEUTIC APPARATUS for operation from the usual 110-volt, 60-cycle current with an oscillatory circuit connected to a spark-gap system which is excited from a step-up transformer.

1,598,663—J. S. STONE, San Diego, California. Filed November 31, 1920, issued September 7, 1926. Assigned to American Telephone and Telegraph Company.

MULTIPLEX RADIO TELEGRAPHY AND TELEPHONY, in which a plurality of pairs of balanced transmitting antennas and a plurality of pairs of balanced receiving antennas are provided, each transmitting pair being conjugate with each receiving pair.

1,598,848—C. C. CHAPMAN, Palo Alto, California. Filed March 24, 1923, issued September 7, 1926. Assigned to Federal Telegraph Company.

RADIO FREQUENCY ARC CONVERTER AND METHOD OF OPERATING SAME. An arc converter is illustrated having a gaseous atmosphere supplied to the arc chamber. The gaseous atmosphere contains hydro-carbon material and an auxiliary heater is provided for decomposing the hydro-carbon and altering the molecular structure of the material.

1,599,453—H. A. AFFEL, Brooklyn, New York. Filed June 24, 1922, issued September 14, 1926. Assigned to American Telephone and Telegraph Company.

ANTENNA STRUCTURE, for operation with a plurality of different wave lengths where a plurality of filters each having different frequency cut off points are connected between the terminating point of the antenna and an outer end thereof, the distance between each of the filters and the terminating point of the antenna being the optimum length of the antenna for the frequency at which the particular filter cuts off.

1,599,471—R. F. KENYON, San Francisco, California. Filed March 7, 1925, issued September 14, 1926.

RADIO RECEIVER, in which a crystal detector is mounted upon a vertical panel and a rock lever provided for permitting the searching of the surface of the crystal.

1,599,586—E. S. PURINGTON, Cambridge, Massachusetts. Filed April 27, 1922, issued September 14, 1926. Assigned to John Hays Hammond, Jr.

RADIANT SIGNALING SYSTEM, whereby a semi-secret method of broadcasting is provided. Oscillations are produced of substantially constant amplitude and then the frequency wobbled and the signals transmitted by alternately impressing signaling current in the wobbled or unwobbled condition in the transmission circuit.

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*Received by the Editor November 22, 1926.

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1,601,065—T. R. GRIFFITH, Dover, New Jersey. Filed October 5, 1920, issued September 28, 1926. Assigned to Western Electric Company.

ELECTRON DISCHARGE DEVICE, in which the cathode is centrally positioned with respect to the cathode and grid and water-cooled by an eternal supply of water to the tube.

1,601,066—J. E. HARRIS, Newark, New Jersey. Filed Dcember 8, 1922, issued September 28, 1926. Assigned to Western Electric Company.

ELECTRIC DISCHARGE DEVICE, in which a cathode is provided, composed of barium and strontium oxides and an oxidized nickel chromium alloy grid.

1,601,070—J. W. HORTON, East Orange, New Jersey. Filed April 18, 1922, issued September 28, 1926. Assigned to Western Electric Company.

WAVE METER, comprising resonant circuits for attenuating the current supplied thereto by different amounts and an indicator. Currents are supplied to the indicator in opposite direction and by controlling the resonant circuits the effective currents supplied to the indicator may be measured, which is proportional to the indication of wave length.

1,601,071—J. W. HORTON, Bloomfield, New Jersey. Filed April 18, 1922, issued September 28, 1926. Assigned to Western Electric Company.

OSCILLATION GENERATOR, in which tubes are coupled in feedback relation and the entire oscillating output energy delivered through a path adapted to limit at a predetermined value the amplitude of the oscillator current. Oscillations of a selected frequency are produced by the current transversing this path and the potential of selected frequency may then be impressed upon the control element of one of the tubes of the system.

1,601,075—A. W. KISPAUGH, East Orange, New Jersey. Filed April 10, 1924, issued September 28, 1926. Assigned to Western Electric Company.

SYSTEM OF SPACE DISCHARGE DEVICES, in which energy is supplied to the electrodes of the tubes in proper sequence and its applications controlled to prevent surges in the circuit of the system.

1,601,109—E. L. CHAFFEE, Belmont, Massachusetts. Filed March 31, 1922, issued September 28, 1926. Assigned to John Hays Hammond, Jr.

MULTI-FREQUENCY RESONANT NET WORK, in which oscillations at different frequencies are impressed upon a net work which comprises reversely arranged couplings for preventing current impulses of one of the frequencies from reacting upon the source of the impulses of the other of the frequencies with means operatively connected with the net work for impressing the energy upon the ether for transmission of signals.

1,601,281—K. J. G. AHLSTRAND, Stockholm, Sweden. Filed May 4, 1926, issued September 28, 1926.

VARIABLE CONDENSER FOR TUNING ELECTRIC OSCILLATING CIRCUITS, in which a hollow spindle is provided with an auxiliary shaft thereon for securing a fine variation in the capacity of the condenser independent of larger variation under action of the main plates.

1,601,300—L. DIAMOND, Oakland, California. Filed July 27, 1925, issued September 28, 1926.

HELICAL PLATE CONDENSER, wherein the special relation of the plates may be varied by axial movement of a condenser shaft.

1,601,313—M. LATOUR, Paris, France. Filed August 19, 1921, issued September 28, 1926. Assigned to Latour Corporation.

VACUUM TUBE RELAY, where a direct current generator is arranged to charge a battery, which in turn delivers energy to the circuits of an electron tube.

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1,603,156—FRANK SEELAU, Detroit, Michigan. Filed October 23, 1924, issued October 12, 1926.

VARIABLE CONDENSER, consisting of flexibly mounted plates movable within a casing with a rotatable device for varying the spacial relation between the plates and the casing.

1,603,184—J. J. AURYNGER, Brooklyn, New York. Filed August 16, 1922, issued October 12, 1926.

CONDENSER, in which the plates are provided with a plurality of perferations having equal electric density throughout with a distributed unit area of plate capacity.

1,603,209—J. H. PAYNE, JR., Ballston Spa, New York. Filed September 30, 1922, issued October 12, 1926. Assigned to General Electric Company.

ELECTRICAL DISCHARGE DEVICE for high power operation consisting of a metallic casing with an electrode supported in the casing and a seal including a vitreous sleeve with a flexible member connecting the electrode and the seal.

1,603,284—J. B. JOHNSON, Elmhurst, New York. Filed November 24, 1924, issued October 19, 1926. Assigned to Western Electric Company.

ELECTRIC DISCHARGE DEVICE, having a fluorescent screen comprising a mixture of zinc salt and calcium tungstate.

1,603,369—T. WHEELER, Chicago, Illinois. Filed May 8, 1924, issued October 19, 1926.

LOOP AERIAL AND THE LIKE, which may be folded into a small compact structure for portable use. The cross arms are each arranged to support the wires in spaced relation at the extremities thereof.

1,603,468—BERLIN-FRIEDENAU, Germany. Filed October 19, 1922, issued October 19, 1926. Assigned to Siemens and Halske.

METHOD OF IMPROVING THE INSULATION OF VACUUM TUBES, by providing an outwardly opening concavity whose walls consist of the same material as that which constitutes the tube. The outer opening of the cavity is closed by means of a non-hydroscopic insulator.

1,603,494—E. S. PRIDHAM and P. L. JENSEN, of Oakland, California. Filed November 8, 1924, issued October 19, 1926. Assigned to The Magnavox Company.

RADIO RECEIVING APPARATUS, in which a plurality of variometers are journaled on separate shafts and connected together by gearing for simultaneous control from a central point.

1,603,582—L. M. CLEMENT, Mountain Lake, New Jersey. Filed May 3, 1921, issued October 19, 1926. Assigned to Western Electric Company.

CARRIER WAVE TRANSMISSION SYSTEM, in which radio toll links are provided for connecting ordinary telephone and telegraph systems for two-way communication. The abrupt switching required in establishing radio toll connections introduces the problem of undesirable surges in the transmitter oscillator, and the invention is directed to circuits for avoiding these difficulties.

1,603,640—WALTER C. REED, Dalton, Massachusetts. Filed May 20, 1925, issued October 19, 1926. Assigned to Radio Products and Specialty Company.

RADIO FIXED CONDENSER, where a central eyelet rivet is provided for holding a plurality of concentric plates under pressure.

1,603,939—W. DUBILIER, New York, N. Y. Filed January 21, 1921, issued October 19, 1926. Assigned to Dubilier Condenser and Radio Corporation.

CONDENSER CONSTRUCTION for fixed electrical condensers wherein high insulation is afforded by the arrangement of a plurality of condenser sections into stacks which are separated from each other by dielectric sheets.

1,604,129—A. MEISSNER, Berlin, Germany. Filed August 8, 1922, issued October 26, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

TRANSMITTING ARRANGEMENT FOR RADIO TELEGRAPHY AND TELEPHONY, in which a plurality of separate paths are provided at different areas of the antenna. These areas are positioned at successively increasing distances from the apparatus and the paths have equal impedances.

1,604,140—H. A. AFFEL, Maplewood, New Jersey. Filed September 19, 1924, issued October 26, 1926. Assigned to American Telephone and Telegraph Company.

MULTIFREQUENCY OSCILLATOR, having a closed path in which the oscillations flow with circuits for determining a primary frequency and tuned circuits for providing a plurality of changes in frequency as the energy flows over the path. The frequencies which result from such frequency changes are not related to the primary frequency as harmonics thereof where an antenna is provided with separate paths connecting the apparatus with different areas of the antenna. These areas are at successively increasing distances from the apparatus and the paths have equal impedances.

1,604,171—C. B. KINLEY, Detroit, Michigan. Filed June 23, 1925, issued October 26, 1926.

CONDENSER OPERATING DEVICE, in which a slidable rack is arranged to operate a plurality of pinions for reciprocating sets of condenser plates with respect to other sets of condenser plates for controlling the tuning of a plurality of circuits.

1,604,403—JOHN H. FLYNN, JR., Cincinnati, Ohio. Filed December 15, 1924, issued October 26, 1926.

RADIO APPARATUS, in which a crystal detector is provided having a reciprocatory contacting arm which may be adjusted in position to select a sensitive point on the crystal.

1,604,508—ZISCH, G. J., West Orange, New Jersey. Filed March 25, 1925, issued October 26, 1926.

VERNIER CONDENSER of the variable plate construction where the sets of plates consist of sectors having progerssively differing areas.

1,604,533—RYAN, C. P., East Molesey, England. Filed February 26, 1924, issued October 26, 1926. Assigned to Vickers Limited.

RADIO CONTROL APPARATUS, which is tuned to the tone frequency of the signals and selectively actuated by incoming signals for closing a local control circuit.

D-71,138—FREDERICK DIETRICH, New York City, N. Y. Filed June 28, 1926, issued September 28, 1926. Assigned to Brandes Laboratories, Incorporated.

TABLE CONE DESIGN as manufactured by Brandes Products Corporation comprising an acoustic chamber and cone with a parabolic sound reflecting chamber enclosing the cone.

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Entered as second-class matter, February 16, 1916, at the Post-Office, at New York, N. Y., under the Act of March 3, 1879.

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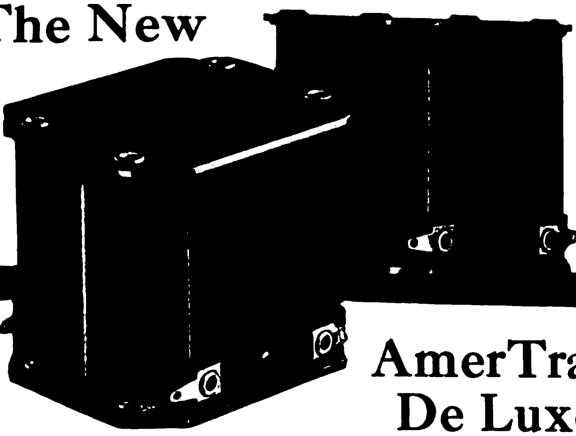
The New



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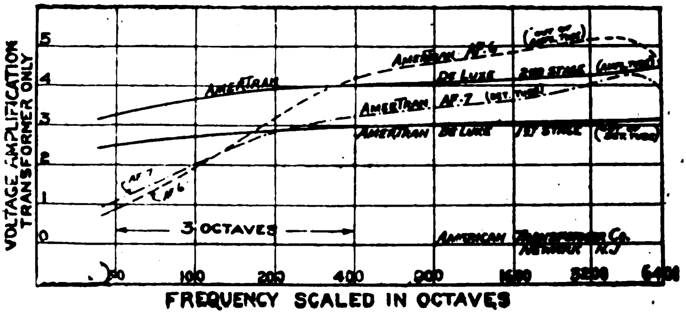

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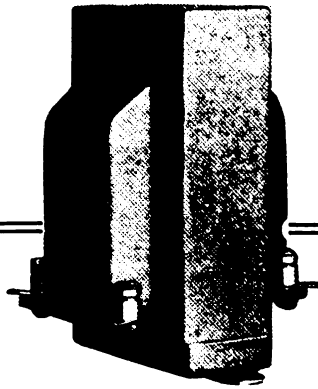

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